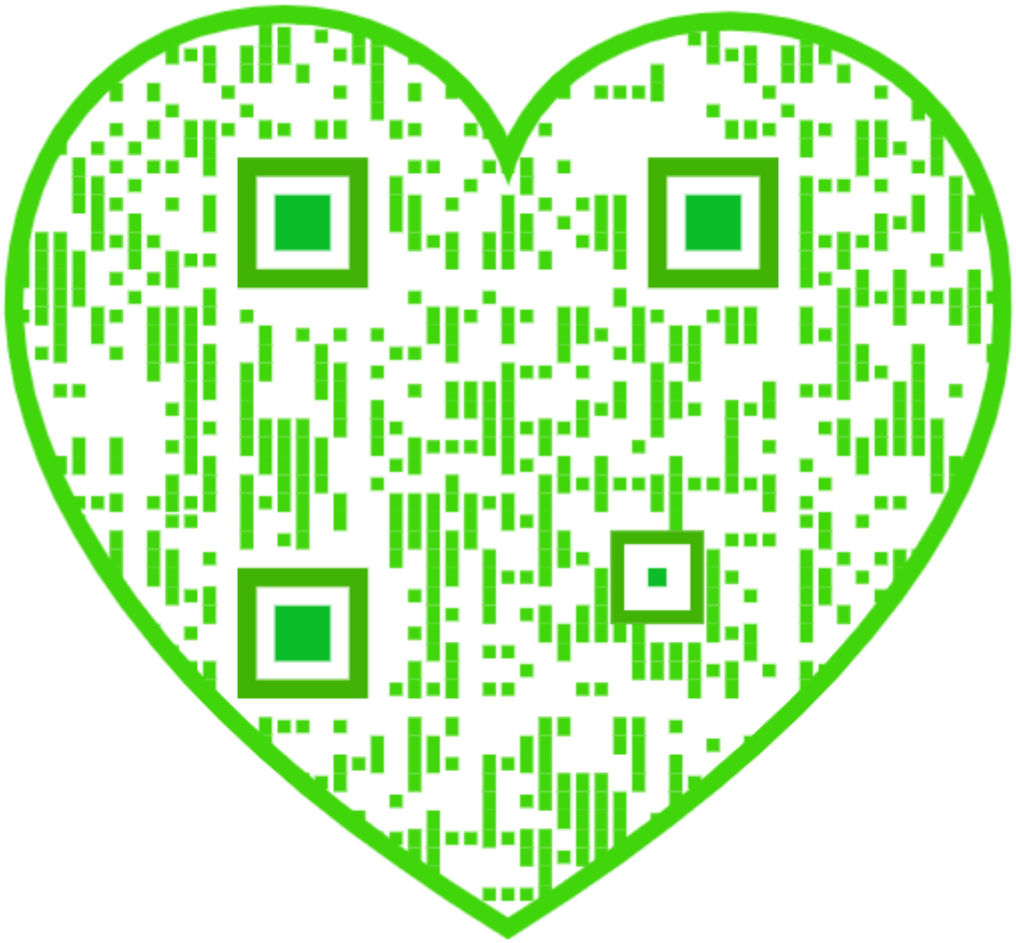

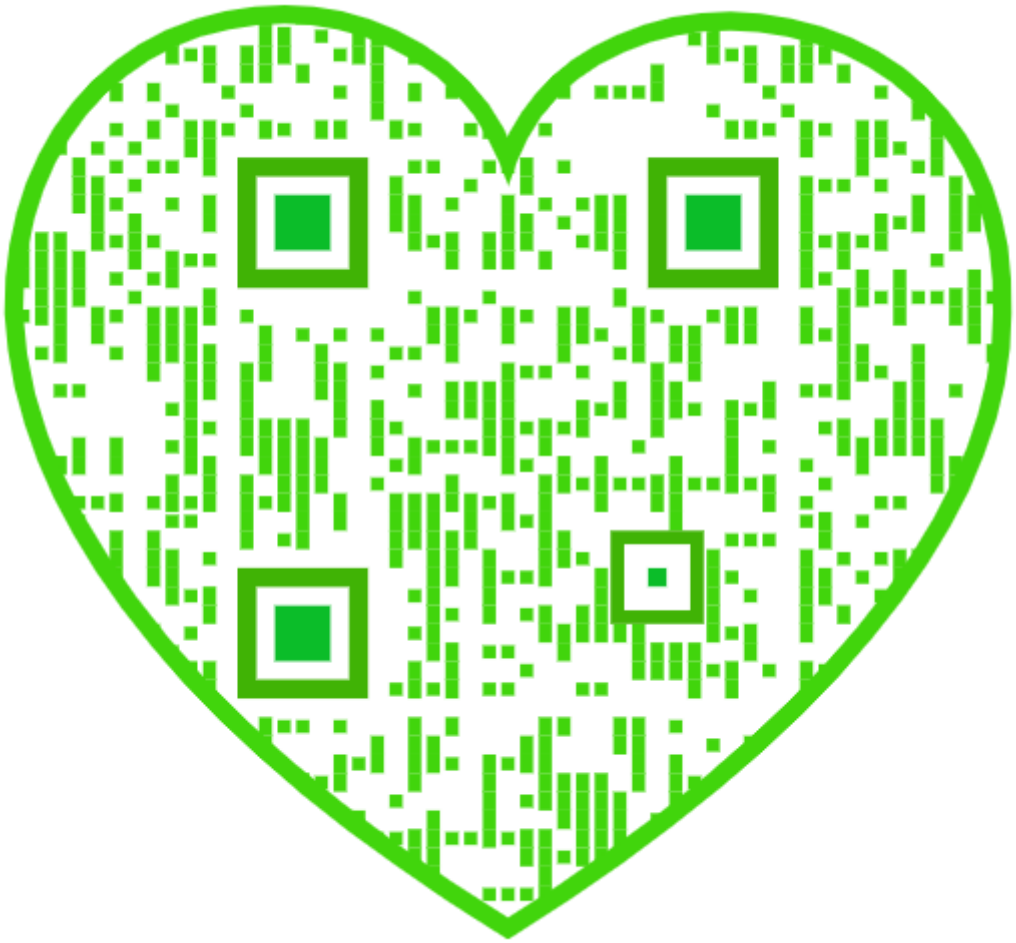

TOOL-MAKING

A PRACTICAL TREATISE ON THE ART OF MAKING TOOLS, JIGS, AND FIXTURES, WITH HELPFUL SUGGESTIONS ON HEAT TREATMENT OF CARBON AND HIGH-SPEED STEELS FOR TOOLS, PUNCHES, AND DIES

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AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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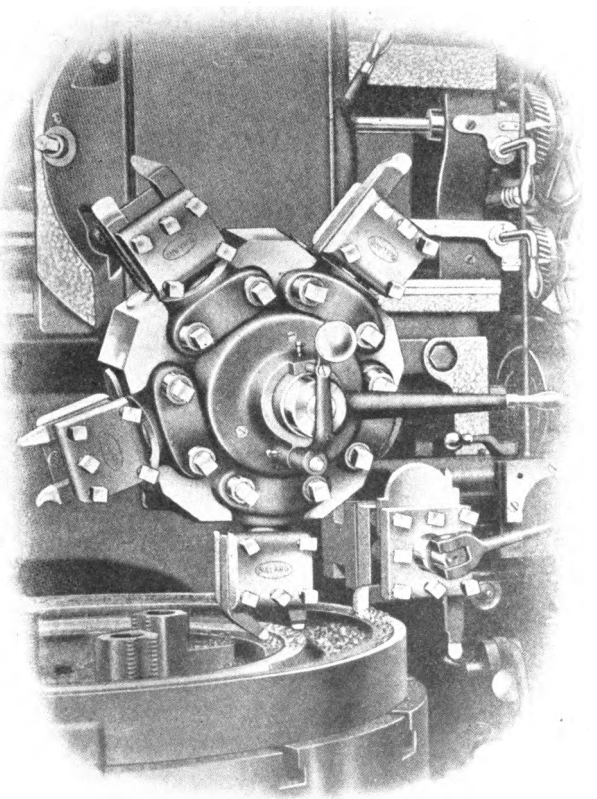
INTRODUCTION

THE history of the development of the tool-making art is, of course, the history of the mechanical development of the country. The hand working tools came first and then with the invention of each successive machine came the creation of tools to go with it. The gradual evolution of machine methods brought an increase in the required accuracy of workmanship and this in turn demanded more precise methods and greater skill on the part of the tool maker. Today, therefore, the large body of so-called "tool makers" represents the most skilled, the most inventive, and the most intelligent of the army of mechanics which forms the back bone of our immense mechanical industries.

¶ Many phases of this mechanical development have increased the importance of the tool maker — the introduction of high-speed steels, demanding greater skill in construction of the tools because of the greater demands upon them; the variation of hardening and tempering methods owing to the variety of steels used; and particularly the use of "production" methods which necessitates the design and manufacture of complicated tools, jigs, and fixtures for the rapid duplication of any given machine. The design of efficient and complete sets of such tools requires highly developed knowledge of machine methods, and a thorough understanding of the machines for which the tools are designed.

¶ The author of this work has had years of experience not only in teaching the subject but in the practical side as well, and is able to give the reader a multitude of helpful suggestions for successfully carrying out the mechanical operations required. It is the hope of the publishers that this work will be found a worthy contribution to our standard technical literature.



APPLICATION OF BULLARD TURRET LATHE FOR RAPID MACHINE WORK
Courtesy of Bullard Machine Tool Company, Bridgeport, Connecticut

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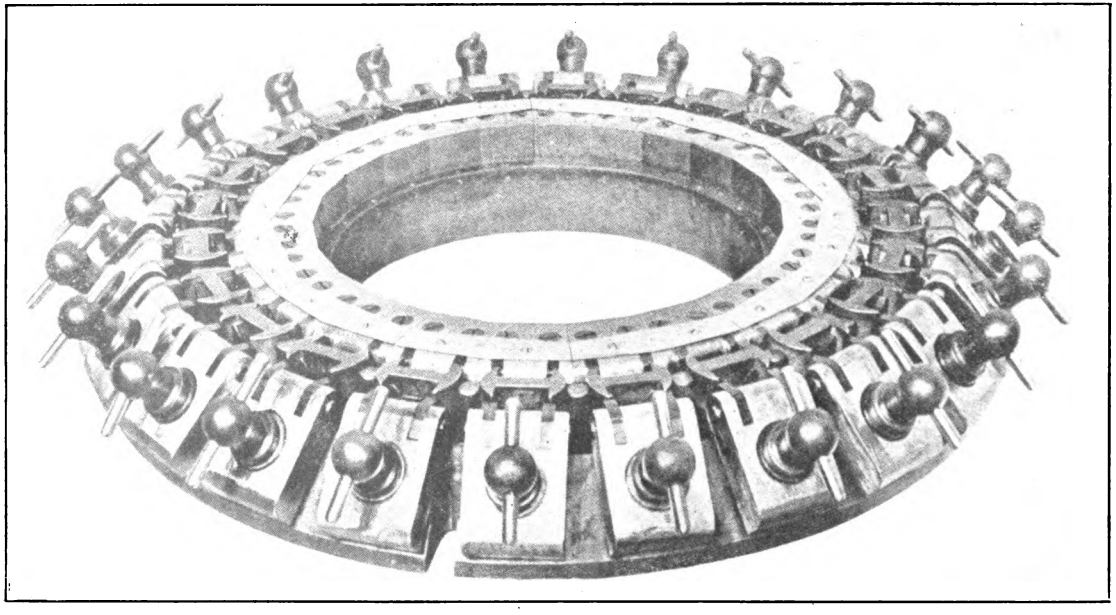


TYPICAL JIG SET-UP ON BECKER MILLING MACHINE FOR MILLING ARMATURE CORES
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

TOOL-MAKING

PART I

INTRODUCTION

THE TOOL-MAKER AND HIS EQUIPMENT

As generally understood, a tool-maker is a machinist who has a greater knowledge of the trade than is sufficient simply to enable him to make such machines or parts of machines as may be the regular product of the shop in which he is employed.

The business of the tool-maker is to make the tools for producing the different parts of machines, implements, or apparatus. It includes the making not only of cutting tools, but also of jigs and fixtures for holding the work while the various operations are being done, and the necessary gages to determine when the different parts are of correct size and shape. It also includes the making of the models for the different fixtures and gages. In some shops where there is work enough on the gages and models, the tool-makers regularly employed on this latter work are termed *gage-makers* and *model-makers*, respectively; yet, in the average shop, it is the tool-maker who makes these tools and such special machinery as may be required.

Fundamental Requirements for Successful Work. *Accuracy in Vital Measurements.* In order to acquire any degree of success, the tool-maker must have not only the ability to work accurately and within reasonable time, but also a knowledge of drafting to enable him to read quickly and exactly any ordinary drawing. Unless he can read decimal fractions readily and correctly, he will experience much difficulty when working to measurements that require accuracy to within .0001 inch. As most of the measuring instruments used by the tool-maker read to .001 inch, and some of them to .0001 inch, or even closer, it will be readily seen that in laying off measurements for gages, models, drill jigs, and similar work, a thorough knowledge of arithmetic is essential.

A tool-maker should be familiar with the accurate reading of the micrometer and of the vernier, as applied to the vernier caliper,

vernier depth gage, and vernier height gage. He must bear in mind, when using the vernier caliper for inside measurements, that it is necessary to add the amount of space occupied by the caliper points *AA*, Fig. 1, to the apparent reading on the vernier side.

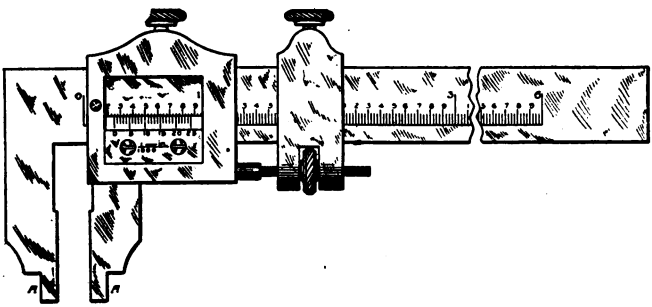


Fig. 1. Vernier Caliper Used for Inside and Outside Work

When measuring the distance between the centers of two holes, as in Fig. 2, set the vernier so that the portions of the jaw marked *AA*, Fig. 1, will exactly caliper the distance from *B* to *B* in Fig. 2. To the apparent reading of the vernier, add the space occupied by the caliper points; and from this subtract one-half the diameter of

Fig. 2. Diagram Showing Method of Measuring Distance between Centers of Holes by Vernier Caliper

each of the holes. It is necessary to caliper the size of each hole. Do not take anything for granted when accurate measurements are necessary. A reamer ought always to cut an exact size, but experience proves that it does not invariably do so. If the size of the hole is taken for granted and a mistake of .002 inch is made, an error of .001 inch in a measurement would result.

Judgment in Approximate Measurements. While extreme care should be exercised when accuracy is essential, there are parts of a tool where approximate measurements will do. If within $\frac{1}{16}$ inch is sufficiently exact, it is folly to spend time to get a dimension within a limit of .0001 inch.

Approximate measurements are those made with the aid of calipers, dividers, surface gage, etc., set to an ordinary steel rule. Precise measurements are obtained by the aid of the various measuring instruments graduated to read to very small fractions of an inch; also by the use of standard reference discs, and standard test bars, accurate within a limit variation of $\frac{1}{10000}$ part of an inch. In using the micrometer, the vernier, or any of the measuring instruments supposed to give accurate readings, it is necessary to exercise great care in setting the tools. In setting the vernier, it is well to use a powerful eyeglass in order that any error in setting may be so magnified as to be readily apparent.

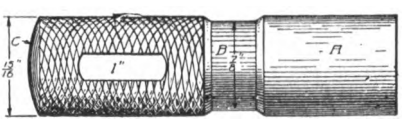


Fig. 3. Plug Gage

The difference between the two characters of measurements described—approximate and precise—may be readily seen in the plug gage shown in Fig. 3. The gage end *A*, when ground and lapped, must be *exactly* 1 inch in diameter, as shown by the stamped size on the handle *C*. The handle should be $\frac{15}{16}$ inch in diameter and knurled, and the neck, $\frac{7}{8}$ inch. While the end marked *A* is necessarily a precise measurement, *B* and *C* are approximate, and an error of $\frac{1}{64}$ inch or more on either diameter would not interfere with the accuracy of the gage. This does not mean that so great an amount of variation from given sizes should ever occur; but the illustration is given to show that the practical workman will never spend an unnecessary amount of time to produce accurate measurements, when an approximate measurement will do. On the other hand, all care possible should be taken when lapping the gage end *A* to size.

Constant Care of Machines. The working parts of any machine that may be running should be kept as clean as possible. Do not allow chips to collect on the shears, V's, of your lathe. If the shears

become roughed or worn, accurate turning cannot be done. Keep the machine thoroughly oiled; clean the oil holes out occasionally with a piece of wire, in order that the oil may get to the bearings. Be sure the centers of your lathe are in good condition; have them to gage; and make certain that the live center runs true before taking any finishing cuts. Try the center gage on your countersink occasionally to see that it maintains its correct shape. Keep the center punch ground to a good point. It is advisable to grind the prick punch used in locating working points in some form of a grinder having a chuck or collet to hold the punch while revolving it against the emery wheel; if the point is not perfectly round, it will be impossible to indicate a piece of work perfectly on the faceplate of the lathe with the center indicator.

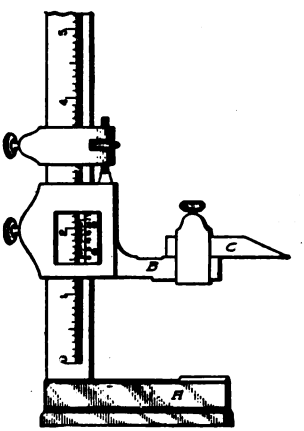


Fig 4 Vernier Height Gage

Necessary Tools. A *vernier height gage*, Fig. 4, is very useful for making drill jigs, templets, and other tools requiring very accurate measurements, and for locating working points, holes, or drill bushings. It is used for obtaining the height of projections from a plane surface, or the location of bushings in drill jigs, etc. The fixed jaw *A* is of sufficient thickness to allow the gage to stand upright. An extension *C* attached to the movable jaw *B* can be used for scribing lines when laying off measurements. In the absence of a height gage, the regular *vernier caliper* may be made to answer the same purpose by making a base which may be attached to the fixed jaw, Fig. 5.

A small *angle iron*, having a *slot* in the upright face to receive a scale for use in connection with a surface gage when laying off measurements is shown in Fig. 6. The slot should be planed perfectly square with the base of the angle iron.

A pair of accurately machined V-*blocks* is a necessary part of

every tool-maker's kit. If made of machine or tool steel, they will not need truing so often as if made of cast iron. After roughing out the V's, every surface should be planed square. They should then be clamped, by means of finger pieces, against the rail on the planer table, the edge of the rail having been previously trued. The head of the planer should then be set to the proper angle, usually 45 degrees, and one of the angles finished; the head may now be set over the opposite way and the other angle faceplaned. The tool used should be ground to give a smooth cut, as it is not advisable to do any finishing with a file or scraper.

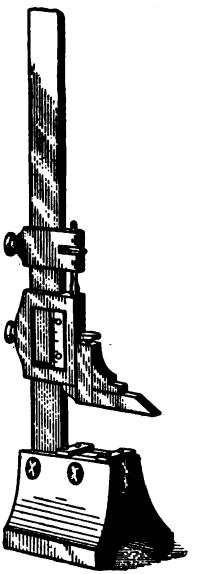


Fig. 5. Special Base Attached to Vernier Caliper

A few small *gages* of the most common angles will be found very convenient, as they can be used in places not accessible to the ordinary bevel protractor; the angles most commonly used are 60 degrees, 65 degrees, 70 degrees, and 80 degrees. The form of gage is shown in Fig. 7. If the tool-maker should be called on to make punch press dies, one or more angle gages, as shown in Fig. 8, will be found very useful.

Many die-makers use an adjustable square having a narrow

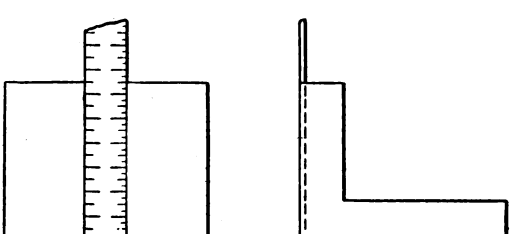


Fig. 6. Attachment for Use with Surface Gage

blade which passes through the aperture in the die. The amount of clearance given is determined by the judgment of the workman

While this method does very well when practiced by an experienced man, it is rather uncertain when attempted by the novice. To get the proper clearance, the beginner should use the gage shown in Fig. 8, called, improperly, a *die-maker's square*. The angle depends on the nature of the stock to be punched and on the custom in the individual shop; but a set of three gages, one 91 degrees, one 91½ degrees, and one 92 degrees, will meet the requirements, as the clearance is seldom less than 1 degree or more than 2 degrees. The angle should be stamped on the wide part of the gage, as shown in Fig. 7. To avoid springing out of shape, the stamping should be done before the gage is finish-filed at any point.

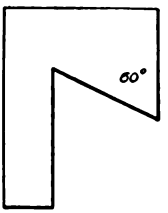


Fig. 7. 60-Degree Angle Gage

The tool-maker should always have at hand a solution of *blue vitriol* for coloring the surface on which he is to draw lines. To make the solution, dissolve in a two-ounce bottle of water all the blue vitriol crystals the water will take up; to this add one-half teaspoonful of sulphuric acid. This produces a copper-colored surface when put on polished steel free from grease and dirt.

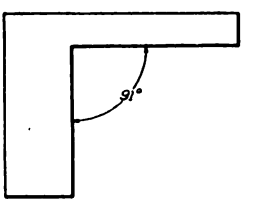


Fig. 8. Die-Maker's Square

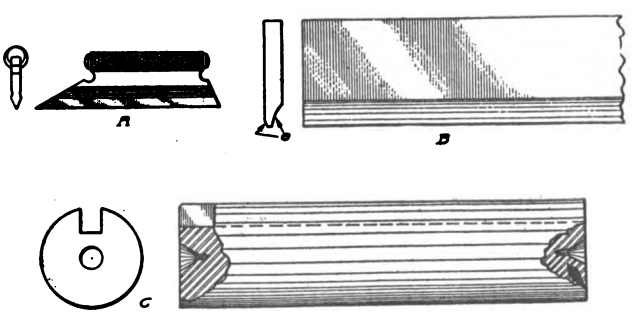


Fig. 9. Forms of Straightedge and Holder for Grinding

A *straightedge* is a necessary part of a tool-maker's kit. Many tool-makers have several, varying in length from 1 inch to 12 inches,

or even longer. The tool should be kept in a case in order that its edge may not become marred. For short straightedges, the form shown at *A* in Fig. 9 is very satisfactory; this is known as a *knife-edge straightedge*. For the shorter lengths, pieces of sword blade answer very well, or steel of the desired form may be procured. Often the longer lengths are made from steel rectangular in shape, one edge being planed or milled, as shown at *B*.

When grinding a straightedge, it is necessary to hold the piece in such a way as to prevent any spring. This may be done by centering a piece of brass or machinery steel, and then milling or planing a groove, as shown at *C*. The blade may be held in the groove by dropping a little soft solder at each end of the blade; if the blade is more than two inches in length, a drop should be placed at distances about one inch apart. As straightedges are usually inclined somewhat in use, it is necessary to grind not only the edge, but the portions marked *e* at *B*. The edge and the corners should be lapped by hand by placing fine emery on a flat bench lap. It will be necessary to finish by oil-stoning any high places that are not removed by lapping. To test the straightedge, try it on a master straightedge, or on a *true surface plate*.

Short straightedges for general use should be hardened to prevent excessive wear and also to prevent the edge from becoming bruised. To harden pieces of this character successfully, clamp pieces of iron to the sides so that from one-eighth to one-quarter inch projects. Then heat to a low red. If the edge is thin, harden in cottonseed oil, plunging the tool beneath the surface of the oil, and working it up and down and around in the oil. If the stock is too thick to harden in oil, use lukewarm water. If a little cyanide of potassium is placed on the edge just before dipping, uniform results will follow.

Master straightedges, 12 inches or more in length, are generally made from steel that is rectangular in cross-section, with the working edge left the full thickness of the stock. The edge is ground in a surface grinder, the tool being held in such a way as to do away with any liability to spring. A very satisfactory holding device is the *magnetic chuck* which precludes all danger of marring the piece. Long master straightedges are usually made from cast iron and are heavily ribbed to prevent springing.

TOOL MATERIALS AND THEIR TREATMENT

Cast Iron. On account of its low cost, cast iron is especially adapted for certain parts of machines and tools. A pattern may be made and a casting of the desired shape and size produced on short notice. As cast iron is a weak, brittle metal, it is not employed for parts that are to be subjected to great strain, unless sufficient metal can be provided to insure necessary strength. At times when a large body of metal cannot be used, the necessary strength may be obtained by constructing ribs to brace the weak portions.

If properly designed, milling machine fixtures, drill jigs, and various other forms of devices used in holding work to be machined, or in holding cutting tools, may be made from cast iron.

Wrought Iron. This metal is but little used in the ordinary machine shop. The low grades of steel, generally known as machine steel, have in a great measure superseded wrought iron. They are stronger, are more easily worked in machining operations, and the first cost is lower than that of good wrought iron.

On account of its fibrous structure, wrought iron does not weaken so readily as steel, under intermittent strain, shock, or blow, and it is more satisfactory under such conditions.

Machine Steel. The ordinary low grades of steel are made by two entirely different processes; and the product of either process, when used in machine construction, or for such work as is generally done in the machine shop, is commonly known as machine steel. As the product of either process may be varied to meet the needs of the buyer, it is apparent that the term machine steel means little, covering as it does every form of iron between wrought iron and tool steel. In order that one may understand the quality of a particular steel, it is necessary to state the percentage of the various elements used in its composition.

The two processes employed in making low-grade steels are the *Bessemer process* and the *open-hearth process*. Steel made by the Bessemer process is known as Bessemer steel, and is made in a vessel known as a Bessemer converter.

Open-hearth steel, a product of the open-hearth furnace, is more costly than Bessemer steel, and is also more reliable. The process being much slower than the Bessemer process, the product is more under the control of the furnace man.

Steel made by either process may be given any desired percentage of carbon; and as carbon is the element in steel that causes it to harden when heated red hot and dipped in water, it is apparent that dead soft steel containing so little carbon that it will not harden, or steel containing a sufficient amount to cause it to harden dead hard, may be produced at the will of the furnace man. Such steel, even though it contains sufficient carbon to cause it to harden as much as tool steel, is not strong enough to stand up under the peculiar strain to which most cutting tools are subjected.

While for certain forms of cutting tools a good grade of high-carbon open-hearth steel answers very well, its use is not to be advocated except where those in charge are sufficiently versed in the nature and peculiarities of the metal to know that it will be satisfactory.

Converted Steel. This metal is many times spoken of as *cemented steel*, and the process used in its production, as the *cementation process*. It is made by packing bars of wrought iron in a receptacle made from some refractory material, the bars being surrounded by charcoal. The cover of the box is sealed, or cemented, with fire clay to prevent the carbon escaping, this operation giving the process its name. The carbon given off by the charcoal is absorbed by the iron, the process being continued until the carbon penetrates to the center of the bars. In the process under consideration, the boxes are placed in a furnace, heated to a yellow heat, and kept at this temperature until the iron is saturated with carbon. Carbon penetrates iron at the rate of $\frac{1}{8}$ inch in 24 hours. Bars $\frac{3}{4}$ inch thick would require an exposure to the carbon for three days (72 hours).

As the steel comes from the furnace, the surface is covered with blisters; hence the product is sometimes called *blister steel*. These bars were laid on one another in piles and the piles were heated to a welding heat, hammered, and welded together into a bar which was called *shear steel*. In case shear steel was cut or broken to short lengths, piled, and welded, the product was called *double-shear steel*. Shear steel was the tool steel of commerce.

Formerly, cast iron, wrought iron, and converted steel were the three forms of iron used in machine construction and in the manufacture of cutting tools.

Crucible Steel. Wrought iron contains considerable slag, which occurs in lines, known as slag lines, running lengthwise of the bar. These slag lines were present in shear steel, and they were a source of annoyance when they occurred at the cutting edge of a tool. It was an English clockmaker, Benjamin Huntsman by name, who first devised a means to obviate this difficulty after experiencing considerable trouble with clock springs made from converted steel. It occurred to him that by melting the steel he might be able to get rid of the slag, as that, being lighter than the steel, would float on the surface of the melted metal. He broke blister steel into small pieces and melted it in a crucible. After the slag was removed the metal was cast into a block called an *ingot*. The ingot was hammered out into a bar called *crucible steel*.

While Hunstman thus founded the crucible steel industry, he met with many serious obstacles which have since been overcome by chemists and steel-mill men; and today, steel, far superior in purity, strength, and general adaptability, to any that has ever been made, is produced by the crucible process.

As the product of the crucible was cast in a mold, the metal was called *cast steel*. As the product of the more recently discovered processes—the Bessemer and the open-hearth—is also cast in molds, unscrupulous makers sometimes stamp their product "cast steel", for the purpose of deceiving the buying public, and good grades of open-hearth steel, which are high in carbon, are sold as "cast steel". As previously stated, such steel may answer for certain purposes, yet for general use a good grade of crucible steel should, as a rule, be used for cutting tools.

Such steel generally proves to be cheaper than cheap grades, even though the first cost may be three or four times that of the cheaper article. Frequently, many dollars' worth of labor is expended on a few cents' worth of steel; and if a poor steel is used, the money expended for labor and steel is thrown away.

In the shop where all steel is tested in the chemical laboratory, it is possible to select stock which contains low percentages of harmful impurities, and whose carbon content is high for many classes of tools. If, however, the percentage of phosphorus is high, such steel is weak, as the effect of phosphorus is to make steel "cold short", that is, to make it weak when cold.

The quality of steel does not necessarily vary much with the price, and some of the very costly steels are, for many purposes, no better than others costing less. It is always advisable to test the steels, select the ones best adapted to the needs, and pay the price.

Preparation of Crucible Tool Steel

Selection of Stock. Tool steel is used for tools intended for cutting, pressing, or working metals or other hard materials to shape. In order to work tool steel successfully, a knowledge of some of its peculiarities is necessary.

Allowance for Decarbonization. Carbon is the element in tool steel that makes it possible to harden it by heating to a red heat and plunging it into a cooling bath. A bar of steel from the rolling mill or forge shop is decarbonized on its outer surface, to a considerable depth; consequently this portion may not harden and if it does, the results are far from satisfactory. For this reason, if a tool is to be made having cutting teeth on its outer surface, it is necessary to select stock of somewhat greater diameter than the finish size, so that this decarbonized portion may be removed. About $\frac{1}{16}$ inch additional for sizes up to $\frac{1}{2}$ inch, $\frac{1}{8}$ inch for sizes up to $1\frac{1}{2}$ inches, $\frac{3}{16}$ inch for sizes up to 2 inches, and $\frac{1}{4}$ inch for sizes above 2 inches, will usually be sufficient.

Various Forms. Tool steel may be procured in almost any form or quality. It is ordinarily furnished in round, octagonal, square, or flat bars. Many tool-makers prefer octagonal steel for tools which are to be circular in shape, but experience shows that steel of various shapes of the same make does not vary materially, provided the quality and temper are the same.

High-Carbon and Low-Carbon Steel. Cutting tools should be made of high-carbon steel if the metal is to be forged or hardened by skilful operators. If the steel is to be heated by an inexperienced man, it is not safe to select a steel having a high percentage of carbon. For non-cutting tools, such as mandrels, a low-carbon steel is better —one per cent carbon or less—because with this steel there is not so great a tendency to spring when hardening.

Hammered Steel. Hammered steel is prized more highly than rolled steel by many fine tool-makers, but authorities do not agree on this point. It is generally conceded, however, that the best tools

can be made from forgings if the heating and hammering have been correctly done. The steel should be heated uniformly throughout, and hammered carefully, with heavy blows at first. Lighter blows should follow, and, when the piece passes from low red to black, great care is needed to avoid crushing the grain. Steel properly heated and hammered has a close, fine grain.

Cutting from Bar. It is advisable, when cutting a piece of stock from a steel bar, to use a cutting tool of some description, such as a saw or cutting-off tool. It is decidedly poor practice to weaken the bar with a cold chisel and then to break it by a sudden blow. This process so disarranges the particles of steel that they do not assume their proper relations with one another when hardened. If it is necessary to cut the steel with a chisel, it is best to heat the bar to a red heat, as in this condition the steel may be cut off without injury.

Centering. When centering, care should be taken that the center-punch mark is exactly in the center of the piece on each end,

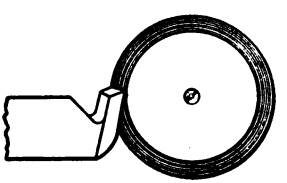


Fig. 10. Effect of Proper Centering

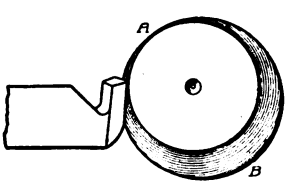


Fig. 11 Effect of Improper Centering

so that an equal amount of the decarbonized material will be turned from all parts of the piece, Fig. 10. If centered as shown in Fig. 11, the decarbonized portion will be entirely removed on the side marked *B*, and will not be removed on the side marked *A;* consequently, when the piece is hardened, the side marked *B* will be hard, while the opposite side *A* will be soft, or at least not so hard as *B*.

Straightening. A piece of tool steel that is to be hardened should never be straightened when cold as it is almost sure to spring when hardened. If it is bent too much to remove all the decarbonized steel when turning to size, it is best, generally speaking, to take another piece of stock. But if the bent piece must be used, heat it to a red heat and straighten.

Annealing. In order that it may be soft enough to work easily, tool steel must be annealed. The process consists in heating the metal to a uniform red heat and allowing it to cool slowly. Steel can generally be bought annealed more cheaply than it can be annealed when needed in the factory.

Annealing removes the strains, or the tendency of the steel to crack and spring when hardened. Strains are caused by rolling and hammering in the steel mill or forge shop. In order to remove the tendency to spring, the piece of steel should be machined somewhere near to size, sufficient stock being left to machine all over after the annealing. If the piece is to have a hole in it, such as a milling machine cutter blank, the hole should be drilled somewhat smaller than finish size—$\frac{1}{16}$-inch is the amount generally allowed—and the piece turned in a lathe to remove all the outer surface which contains the marks of the hammer or rolls. The piece is now ready for annealing, which may be done in one of several ways.

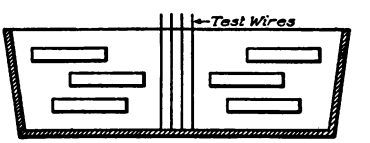


Fig. 12. Diagram Showing Method of Annealing Tool Steel

Box Annealing with Charcoal. For this method, it is necessary to have a furnace large enough to hold an iron box of a size sufficient to take the piece to be annealed. To do the work cheaply, enough pieces should be annealed at a time to fill one or more boxes, according to the capacity of the furnace.

The material used in packing the box is wood charcoal, which should be ground or pounded until the particles are about the size of a pea. A layer of charcoal covering the bottom to a depth of 1 inch is first placed in the box, then a layer of steel. The different pieces of steel should not come within $\frac{1}{2}$ inch of each other, nor within 1 inch of the box at any point. The spaces between the pieces are filled with the charcoal, and they are covered to a depth of 1 inch. Another layer of steel may be put in, if the box is of sufficient size. When within $1\frac{1}{2}$ inches of the top, the remaining space is filled with charcoal, the whole tamped down, the cover put on, and the edges luted around with fire clay to prevent the direct heat of the fire entering the box.

There should be several ¼-inch holes drilled through the cover near the center, and through each of these, a piece of $\frac{3}{16}$-inch wire should be placed, as shown in Fig. 12. The wires should extend to the bottom of the box and project about 1 inch above the top of the cover, so that they may be readily grasped by the tongs. These wires are to be drawn from the box and tested in order to determine the temperature of the contents. The box should be placed in the furnace, and after it has become thoroughly heated, one of the wires is drawn out by means of a pair of long tongs. If no such tongs are available, the legs of ordinary tongs may be lengthened by pieces of gas pipe. If the wire is not red hot, the heating process should be continued for 10 or 15 minutes longer. Then another wire is drawn, and the process kept up until a wire is drawn that is red the entire length. The work should be timed from the moment the box is heated through; this is shown by the wire.

The heat should be maintained a sufficient length of time to insure a uniform heat, which should not be allowed to go above a full red. The length of time the pieces remain in the fire depends somewhat on the size; for steel 2 inches or less in diameter, one hour after the box is heated through will do; larger pieces require a little longer time. After running for the necessary length of time, the heat should be shut off, and the boxes allowed to cool slowly; the pieces should be left in the box until cold.

This method of annealing gives satisfactory results with large pieces to be used for certain purposes, but for light, thin materials, its use is not advised, as the steel remains red hot for too long a period. When articles of this description are annealed, they should be heated to a low red, then placed in an iron box having two or three inches of hot ashes in the bottom, the hot ashes being used to prevent chilling.

Box Annealing with Ashes or Lime. When there are no facilities for annealing by the method above described, the steel may be heated to a uniform red and placed on a piece of board in an iron box, there being one or two inches of ashes under the board. A second piece of board should be placed on the steel and the box filled with ashes. The pieces of wood will smolder and keep the steel hot for a long time.

Another common method of annealing tool steel is to heat the piece to a red heat and bury it in ashes or lime. To secure satis-

factory results the ashes or lime should also be heated, which can be accomplished by first heating a large piece of iron and then burying it in the contents of the annealing box. When the steel to be annealed is sufficiently heated, the piece of iron may be removed and the piece to be annealed put in its place, and thoroughly buried in order that it may take a long time in cooling. It should be allowed to remain in the ashes or lime until cold.

Water Annealing. There is another method of annealing practiced in some shops, known as the water anneal, which answers in an emergency, but is not recommended for general use. The piece of steel is heated to a low red, making sure that the heat is uniform throughout. It should be removed from the fire and held in the air where no draft can strike it until not a trace of red can be seen when the piece is held in a dark place. It should then be plunged in water and allowed to remain until cold. Better results may be obtained if it is plunged in soapy water or oil.

Strengthening Steel by Annealing. In a previous paragraph it was stated that there are reasons for annealing steel other than to soften it. It may be necessary to impart some quality that can be given only by annealing; it may be necessary to toughen and strengthen a spindle or other piece, and at the same time, to have it workable. Use of the following method will secure such results.

The steel is heated red hot and plunged into oil where it is allowed to remain until cool; it is then heated again to a *low red*, removed from the fire, and allowed to cool in the air where no draft can strike it, and where no moisture can come in contact with it.

Steel annealed by this method is very tough, yet it can be bent to a greater degree than if annealed by any of the other methods.

Hardening. Tool steel may be hardened by heating to a low red heat and plunging in some cooling medium, as water, brine, or oil.

Use of Pyrometers. *Necessity for Accurate Temperature Readings.* At the present time, when so much attention is given to obtaining exact temperatures in the various processes of heat-treating steel some form of temperature gage is absolutely essential. The gage used for determining high temperatures is called a pyrometer.

A good pyrometer is a necessity, if the heating of steel is entrusted to a man who has not had a wide experience in gaging

temperatures with the eye. It is also a great aid to the skilled man, as furnace conditions vary. Changing degrees of light in the hardening room may deceive even the most experienced hardener; a man's physical condition may affect his vision; or any one of a dozen things may cause him to heat steel to a temperature that will not produce the best results possible.

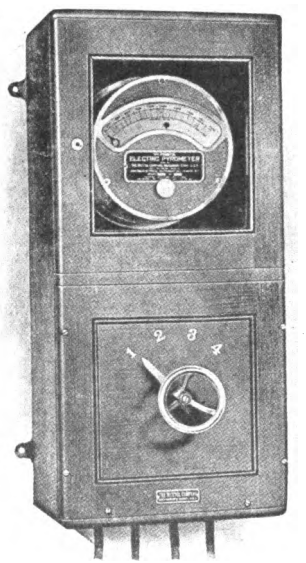


Fig. 13. Electric Pyrometer Which Registers Temperature in Four Different Furnaces
Courtesy of The Bristol Company, Waterbury, Connecticut

In a hardening room having several furnaces, it is not always necessary to provide a pyrometer for each furnace, as a number of furnaces can be connected with one instrument so that by moving a switch each furnace is connected in turn and its temperature can be read from the indicator.

As so much depends on the accuracy of the gage used in temperature readings, it is always best to have one that is known generally as a reliable instrument. The extremely high temperatures to which the fire ends of these gages are subjected, makes it necessary to watch very closely even the most satisfactory makes, for an instrument of this kind, unless fairly accurate, is worse than none.

When using a pyrometer for gaging heats, the fire end should be located as nearly as possible at the same height as the work being heated in the furnace. The temperature in a furnace varies many times; that is, it may be much higher 18 inches above the floor of the furnace than it is at the floor level, and if the work rested on the bottom and was but 2 or 3 inches in height, and the fire end of the

gage was located 18 or 20 inches above the work, the readings might not accurately indicate the temperature to which the piece was heated.

Clay Cones. In order to make sure that the instrument is recording correctly, it is a good plan to check it occasionally with one of known accuracy; or, in the absence of a second gage, it may be checked by means of clay temperature determining cones, called by some *sentinel pyrometers*. The cone should be located as nearly as possible at the same height as the fire end of the pyrometer. When making the test, have the furnace at a temperature somewhat lower than the fusing point of the cone, gradually raising the temperature until the cone fuses. Notice at the fusing time the reading of the

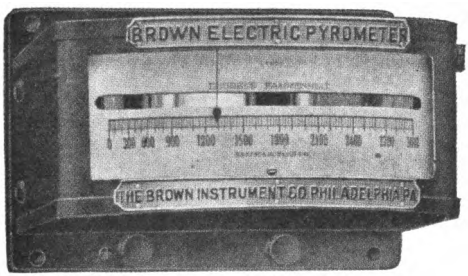


Fig. 14. Electric Pyrometer Which Registers Temperatures up to 3000 Degrees Fahrenheit
Courtesy of the Brown Instrument Company, Philadelphia, Pennsylvania

pyrometer; if the reading agrees with the predetermined fusing point of the cone, it is reasonably certain that the other readings of the gage are correct. Some hardeners, however, insist on testing at several different temperatures, say at 1350° F., 1850° F., and 2250° F., asserting that if the three readings are correct they know the gage is absolutely reliable at the time at any temperature.

The cones are convenient also where there is no pyrometer, as high temperatures may be accurately gaged by their use. Clay cones are cheap, reliable, and easily obtainable in a large range of temperature determinations. Each cone has marked on it its fusing point, so that there is absolutely no need of error in its use.

Various Types. There are a number of satisfactory makes of pyrometers on the market, any one of which will show satisfactory

results if given the same consideration a careful workman is supposed to give any tool or machine used for accurate gaging. Fig. 13 shows a pyrometer that may be employed in gaging the temperatures of four different furnaces. Each furnace is numbered and its fire end is joined by means of wires to the proper connections on the pyrometer. By turning the pointer to the proper number, the temperature of that furnace is shown on the dial of the gage.

Fig. 14 illustrates another style of pyrometer which gages temperatures to 3000° F. By use of the switchboard shown in Fig. 15,

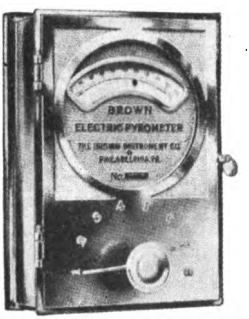


Fig. 15. Switchboard for Manipulating Pyrometer Readings in Various Furnaces

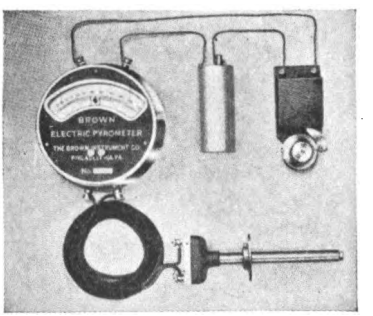


Fig. 16. Brown Alarm Pyrometer

Courtesy of Brown Instrument Company, Philadelphia, Pennsylvania

this gage may be used to determine the temperatures of eight furnaces.

Fig. 16 shows an alarm pyrometer. This can be set to have the alarm ring when the furnace temperature rises or falls beyond the desired limits. Such an instrument is especially desirable where temperatures must *not* exceed certain limits, as is the case with certain high-grade carbon and alloy steels, and where tools and other articles that are to resist great strains are being hardened.

Hardening and Tempering Crucible Tool Steel

After the determination of the proper proportion of carbon, the next important process is the hardening of the steel. This is subdivided into two main processes—heating, and subsequent cooling.

Heating. A piece of steel should never be heated more than is necessary to give the desired result. The heat required varies with the make of steel, the amount of carbon it contains, the size and shape of the piece, and the purpose for which it is to be used. Much depends on giving a piece of steel a *uniform heat throughout.* The edges and corners should be no hotter than the center, and the interior should be of the same temperature as the surface; if not, the piece is likely to crack in the cooling bath, on account of the uneven changes which take place in the molecular structure. While it is highly important that the steel be heated no more than is necessary, yet it is of much importance that it be heated uniformly.

If the steel is placed in an ordinary forge, be sure that the air from the blast does not strike it. For a large piece, build a big, high fire; have it well heated through before putting in the steel. Use the blast only enough to keep a lively fire, and see that the steel is well buried in the fire in order that the air may not strike it.

Steel should always be hardened at a heat that leaves the grain fine when the piece is broken. This condition can be determined by hardening and breaking a small piece from the same bar. A coarse grain denotes a heat higher than the steel should receive.

It will be found necessary, when heating some kinds of steel, to put the articles in an iron tube so that the air cannot come in contact with them; this is especially true when hardening such tools as taps or formed mills, whose outer surfaces cannot be ground, because the oxygen in the air, acting on the carbon at the surface of the piece of steel, burns it out, leaving the surface decarbonized. Better results can be obtained with any tool if it is kept from the action of the fire when heating for hardening.

Cooling. When the piece is uniformly heated, it should be plunged into a suitable bath to give it the proper hardness. It must be worked rapidly up and down or around in the bath, to prevent the steam generated by the red-hot steel from forming at any point and so preventing the liquid from coming in contact with the piece, and also to bring the piece constantly in contact with the cooler parts of the bath. If the piece is long and slender, it must be worked up and down; if it is short, with teeth on the outer edge, as a milling-machine cutter, it should be worked around rapidly, so that all the teeth may be cooled uniformly. If it is flat and has a

hole through it whose inner walls must be hard, it should be swung back and forth so that the bath may pass through the aperture and at the same time strike both faces.

Delicate articles and tools having long projections or teeth, should not be dipped into a bath of very cold water or brine; for such work, a tepid bath gives better results.

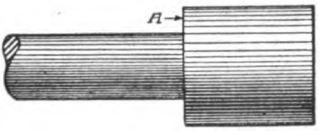


Fig. 17. Tool with Outside Shoulder

If the tool is not to be hardened all over, and it is necessary to heat a larger portion of it than is to be hardened, dip the piece into the bath so that a trifle more of the tool is immersed than is to be hardened, and then work it up and down a little. If this is not done, there will be a line where the piece is expanded on one side and contracted on the other. The steel is likely to crack on this line which is called a *water line*.

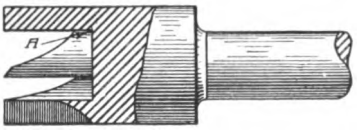


Fig. 18. Tool with Inside Shoulder

When hardening a piece having a shoulder *A* on the outside, as shown in Fig. 17, or inside, as shown in Fig. 18, hardening should not stop at the shoulder, as the unequal strains occasioned by the contraction of the hardened part at the shoulder are likely to cause it to crack at that point. The piece ought not to be hardened as high as the shoulder; but should it be necessary to do so, it is well to harden a little beyond.

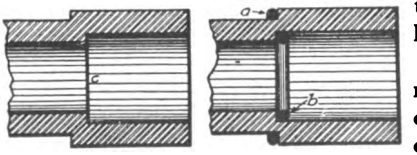


Fig. 19. Use of Wire Ring in Hardening Piece with Shoulder

A very satisfactory method, when sharp corners with sudden changes of sizes occur, as shown in Figs. 17 and 18, consists in placing a ring of wire in the shoulder, as shown at *a* or *b*, Fig. 19. Usually, the piece will be made as at *c*, for the sake of strength, but when two shoulders come in line as shown at *a* and *b*, wires may be placed at both shoulders. The wires, heating with the work, will be red hot

when the piece is dipped into the bath, and will prevent the water attacking the steel too suddenly in the shoulders.

Citric Acid Bath. An excellent bath for hardening small pieces may be made by dissolving one pound of citric acid crystals in one gallon of water. The liquid should be kept tightly covered when not in use, or it will evaporate. Small tools heated to a low red heat and dipped into this solution harden more uniformly than when immersed in clear water.

Pack Hardening. This method gives excellent results with pieces that cannot be hardened by the methods ordinarily employed without risk of springing or cracking. The article is packed in an iron box, with some carbonaceous material, and subjected to the action of heat, to allow it to absorb enough carbon to harden in oil. While this method is not generally used, it is very valuable when hardening such pieces as milling-machine cutters, blanking dies for punching presses, gages, and taps, where it is necessary that the diameter and pitch should not be altered. The carbonaceous material is charred leather, which should be ground or pounded very fine (usually about one-half the size of a pea). An iron box somewhat larger each way than the piece to be hardened, should be selected. A layer of the packing material one inch deep should be placed in the bottom of the box, and the piece of steel laid on this; the box should then be filled with the packing material and tamped down. The space between the cover and the box should be filled with fire clay, which seals it so that the gases in the box cannot escape and the direct heat of the fire cannot get into the box.

It is much more economical to pack a number of pieces at a time, as several may be hardened at the cost of one, and at a saving in packing material. The pieces should be wired with ordinary iron binding wire of a size sufficient to sustain the weight when the wire is red hot, one end of the wire projecting over the outside edge of the box and covered with the luting of fire clay. Several holes should be drilled near the center of the cover for test wires, as in annealing. The wires should extend to the bottom of the box which may now be heated sufficiently to charge the pieces with carbon. As steel does not commence to absorb carbon until it is red hot, the time is determined by means of the test wires as described under "Annealing". For ordinary tools $\frac{1}{2}$ inch in diameter and under, run from 1 hour to

1½ hours after they are red hot; pieces from ½ inch to 1 inch in diameter, 2 to 2½ hours; pieces from 2 to 3 inches in diameter, 2½ to 4 hours. This schedule must be varied according to the nature of the work.

After remaining in the furnace the desired length of time, the box should be taken out, the cover removed, and the piece taken out by means of the wire attached to it. It should then be immersed in a bath of raw linseed oil or cottonseed oil, and worked around until the red has disappeared. Finally it is lowered to the bottom of the bath and allowed to remain until cold.

When a piece of steel 1 inch in diameter, or larger, is hardened, it should be reheated over the fire immediately on being taken out of the bath; this is to avoid cracking from the strains caused by molecular changes which take place after the outside surface is hardened and unable to yield to the internal strains. Reheating the surface to a temperature of about 212 degrees will accomplish the desired result without materially softening the steel.

Although charred leather is the carbonaceous material usually employed in pack hardening, it is not advocated for steel containing more than 1¼ per cent carbon. If steel contains a larger percentage than this, the packing material should be charred hoofs, or charred hoofs and horns. The charred leather may be used over and over, by adding fresh material as the old wastes away. It is advisable to place the fresh material in contact with the steel.

Tempering. The hardening of a cutting tool makes it too brittle to stand up well when in use, and consequently it is necessary to reduce the brittleness somewhat. This process of softening, known as *drawing the temper*, is accomplished by reheating to the proper temperature, ordinarily determined by the color of the surface of the tool which must be brightened previous to the operation. As the piece of steel is heated, a light, delicate straw color appears; then, in order, a deep straw, light brown, darker brown, light purple, dark purple, dark blue, pale blue, blue tinged with green, and, finally, black. When black appears, the temper is gone. These colors furnish a guide to the condition of hardened steel, and indicate the tempers attained with the degrees of temperature used in the various connections shown in Table I.

TABLE I

Color Indications of Temper

Color	Heat (Degrees Fahrenheit)	Usage
Straw, light	430	Lathe and planer tools; scrapers for brass; etc.
Straw, deep	460	Milling cutters; reamers; large taps; etc.
Brown	500	Twist drills; drifts; flat drills for brass; etc.
Purple, light	530	Augers; screw slotting saws; etc.
Purple, dark	550	Saws for wood; cold chisels; screwdrivers; etc.
Blue, dark	570	
Blue, pale	610	
Blue, tinged with green	630	

Heating in Oil. When steel is tempered in large quantities the method just described is expensive. It is not, moreover, so reliable as heating the articles in a kettle of oil, using a thermometer to indicate the temperature. A piece of perforated sheet metal or wire cloth should be used to keep the articles two or three inches from the bottom of the kettle. A perforated sheet-iron pail two inches smaller in diameter than the kettle, resting on a piece of iron, or a frame placed in the bottom, will keep the pieces from the sides and bottom of the kettle. The thermometer should be placed in the kettle outside the pail, in order that the bulb may be at the same depth as the lower pieces.

Spring-Tempering. A piece of steel may be spring-tempered by first hardening and then drawing the temper to such a degree that the piece, when bent, will return to its normal shape after the pressure is removed. This may be accomplished by covering the surface with tallow or some animal oil, and then heating until the oil catches fire from the heat in the piece.

Casehardening. *Heating with Powdered Cyanide of Potassium.* When an article of wrought iron or machine steel is to have a hard surface, it is treated while red hot with some material that forms a coating or case of steel, which hardens if dipped into water while red hot. Small articles, such as nuts, screws, etc., may be casehardened by being heated red hot and covered with a thin layer of powdered cyanide of potassium. When the cyanide of potassium melts, the article should be heated red hot again and plunged into water. Care should be exercised when using the cyanide, as it is extremely poisonous.

It is sometimes desirable to harden a piece by this method, and to have the surface colored. This may be accomplished by having the surfaces first perfectly clean and well polished. Then, when heated, and cyanide has been applied and allowed to "soak in", the piece is dipped into a bath of clean water. Before dipping, place a piece of pipe in the water, blow through the pipe, and dip the article down through the water where the air bubbles are coming to the surface. The air in the water helps to produce a mottled appearance on the surface.

Heating with Bone and Charcoal. The process described is suited for hardening a few pieces quickly, but it is not recommended for large quantities of work. When many pieces are to be case-hardened at a time, the following method will be found less expensive and far more satisfactory:

Granulated raw bone and granulated charcoal are mixed in equal quantities, or one of the several good commercial case-hardening compounds now on the market may be used. Some of these compounds are more rapid in action than bone, and most of them are cheaper. But whether one of these or bone is used, the same general instructions are to be observed.

A layer of the mixture is placed in an iron hardening box to the depth of 1 or $1\frac{1}{2}$ inches, and on this the articles to be hardened are placed. The pieces should not come within $\frac{1}{2}$ inch of each other, or within 1 inch of the walls of the box at any point; they should be covered with a layer of the mixture to the depth of $\frac{1}{2}$ inch. Successive layers of articles and mixture are placed in the box up to within 1 inch of the top, the remaining space being filled with packing material; the cover is then put in place and the edges luted with fire clay. Test wires should be used as described for annealing. The heating must be timed from the moment when the contents of the box are red hot, as determined by the test wires. The length of time the work is allowed to run while red hot depends upon the desired depth of the hardened surface; generally carbon will penetrate wrought iron $\frac{1}{8}$ inch in 24 hours; but as it is rarely necessary to harden deeper than $\frac{1}{32}$ inch, the work may be kept red hot from three to four hours. With small pieces, the contents of the hardening box may be dumped into a tank of running water; if the pieces are large, it is necessary to dip them one at a time just as in the case

of tool steel. For extreme toughness, the pieces, if small, may be dumped into a perforated sheet-metal pan and the packing material sifted out, after which they should be placed in a bath of oil. If not sifted out, the packing material will stay at the top of the oil and set fire to it.

When a fine grain and strength are desired in the casehardened portion, it is advisable to pack the articles in the hardening box as described, then to heat them in a fire for a period that insures the desired depth of penetration of carbon. The work is then allowed to cool in the box, after which it is removed, heated in the fire, and hardened by dipping in the water or oil bath.

At times, charred bone should be used instead of raw bone, as the charred bone makes the hardened article stronger. For colored surfaces charred bone mixed with charred leather is extensively used. If we wish to harden for colors, it is necessary to employ comparatively low heats and to hold the box very close to the top of the bath when the work is dumped, in order that the pieces may not be exposed to the oxidizing action of the air. It is not advisable in making colored surfaces to allow air to come in contact with heated work passing from the box to the bath, but if air is introduced into the hardening bath excellent results may be obtained. In Fig. 20 is shown an air pipe which enters the bath with the water supply, the air being forced in by a pump.

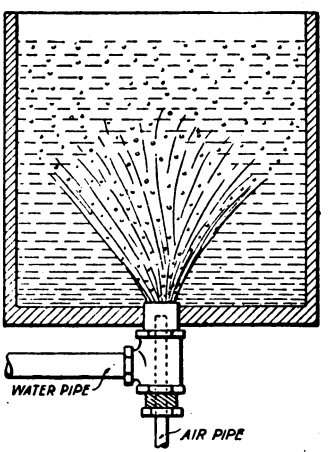


Fig. 20. Hardening Bath with Air Supply

In order that work may not go into the bath in a mass, the contents of the box should be shaken out, a few pieces at a time, or wires should be located along the top of the tank to separate the articles so that the liquid can act on each piece. The bath must be deep enough to allow the articles to chill below a red before striking the bottom, or unsatisfactory results will follow.

Heating in Melted Cyanide of Potassium. Cyanide of potassium may be melted and heated red hot in a cast-iron crucible or pot, and pieces of work suspended in it until they are red hot, when they should be removed and plunged into the water to harden.

Beautiful colors may be obtained by this method, if the surfaces of the work are nicely polished and cleaned before it is placed in the cyanide. The heat should be low, and the articles should be passed through a spray and then into a tank of clear water. In order to get the spray, Fig. 21, it is necessary to have a supply pipe coming down from above the tank with the end so flattened as to make a long and very narrow opening.

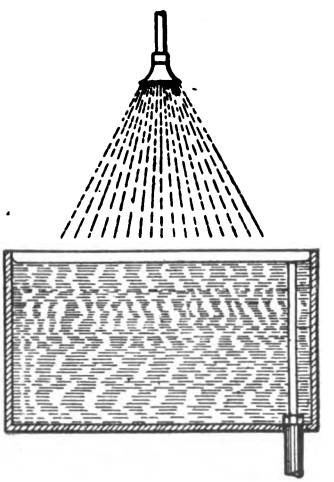


Fig. 21. Water Spray for Cyanide Bath

If colors are wanted, and a hardened surface is not, use in the crucible what is known as "50 per cent" fused cyanide. Unless the steel is sufficiently high in carbon to harden of itself, the surfaces will not harden.

Alloy Steels

The tool steel that is generally used for cutting tools is made by the crucible process. If the steel depends on the carbon in it for its hardening qualities, it is called *carbon tool steel.* High-carbon steels harden better, stand higher speeds, and allow heavier cuts than the same quality of steel with lower carbon percentages.

In order to produce a steel that will stand higher speeds and heavier cuts than carbon steel, various elements have been added. Each of these steels are generally given a distinguishing name, usually that of the added element, such as vanadium steel, manganese steel, silicon steel, tungsten steel, etc.

Vanadium steel is especially adapted to such tools as taps, reamers, broaches, and some forms of dies.

Tungsten Steel. If tungsten is added in a small percentage, a steel is produced that allows higher speeds and will cut harder stock. Steel with a higher percentage of tungsten hardens if heated red hot and allowed to cool in the air, but better results follow if it is cooled in an air blast, or in oil. This is called *air-hardening* or *self-hardening* steel. Tools made from air-hardening steel allow speeds from 50 to 60 per cent higher than can be obtained from similar tools made from carbon steel. This steel proves particularly satisfactory for heavy roughing cuts, but not for finish cuts as it does not hold a fine cutting edge. It has given way to the modern high-speed steel in most shops, but for certain classes of work it is still used to some extent.

Oil-Hardening Steels. Carbon tool steels, when hardened by the ordinary fire-and-water method, show a tendency to get out of shape, or to change in length measurements. To do away with this difficulty, oil-hardening steels are extensively used in many shops for making taps, dies for screw cutting, blanking dies for punch-press work, etc. Under many conditions these steels work very satisfactorily, if a brand adapted to the particular work to be done is procured. The method of treatment for the steel of different makes varies so much it would not be wise to attempt to give any specific instructions without knowing the particular make of steel and the purpose for which it is to be used. The makers of these special steels always furnish instructions for working their particular brands, so there need be no difficulty encountered in their use. Directions should be carefully followed, except in cases where experience has shown the advisability of a different method. To secure the best results, a furnace equipped with a good pyrometer should be used, as this enables the operator to adjust the temperature to the proper point.

To show the variation in treatment for the different makes of alloy steels, we shall cite two cases, both well-known brands. One make that is specially adapted for taps, dies, and similar tools should be hardened at a temperature of 1350° F., while another make, to be used for the same purpose, shows best results when hardened at 1500° F., a variation of 150 degrees. Yet both steels give excellent results when treated according to instructions.

Modern High-Speed Steels

If, besides tungsten, certain proportions of chromium are added, a steel is produced that has revolutionized machine-shop methods. It allows extremely high speeds, heavy cuts, and coarse feeds. It is possible with a good grade of high-speed steel to increase the cutting speed of tools from 50 to 200 per cent above that possible with ordinary carbon steel. Unlike carbon steels, the high-speed steels grow harder as they become heated, until they are red hot when they are soft enough to forge.

Forging. This steel should not be heated too rapidly; in fact, it requires comparatively slow, careful heating in a good, heavy fire of blacksmithing coke. It should be worked at a high heat, with rapid blows, which should cease as the temperature goes down. *Never hammer when the steel is at a low red.* Although the steel should be reheated as soon as it is below a forging heat, as much as possible should be done at each heat.

After forging, the tool should be reheated to a high red heat, and allowed to cool slowly in the air; this is done to remove forging strains which might cause the steel to crack when hardened. When the tool has cooled down below a red, place it in the fire, and reheat for hardening.

Variations in Hardening for Different Tools. When hardening tools made from high-speed steel, it is necessary to vary the treatment to suit the particular class of tool. For instance, it is customary to heat ordinary *lathe* and *planer tools* nearly to the fusing point; in fact they are usually brought to a temperature that causes the edges and corners to drip, then placed in a strong blast of air, or dipped in cottonseed oil. When hardening *reamers, taps, drills, milling-machine cutters,* and other tools having slender projecting portions, or standard forms, it is not possible to heat them to such a temperature and preserve the shapes and slender portions, as they would be melted away; neither can they be cooled in an air blast, as the action of the air is to oxidize the slender portions and so to render the tool unfit for use. Most tools used in the lathe, planer, and similar machines, can be ground to shape after hardening, and the melting-away of the edges and corners does little or no harm; but taps, dies, reamers, and formed milling cutters must retain their shapes as they cannot be ground to form after hardening.

Lathe and planer tools of ordinary design may be heated in a fire of coke or well-coked blacksmith's coal, in an ordinary forge, although better results are obtained if they are heated in a furnace specially designed for high-speed steel; long slender articles, such as taps and reamers, give best results if heated in a furnace of the design shown in Fig. 22. This furnace is so constructed that the flame moves around the walls thus leaving a space at the center free from the direct flame. The tools are suspended from the top as shown and in the center, thus preventing oxidation of the steel.

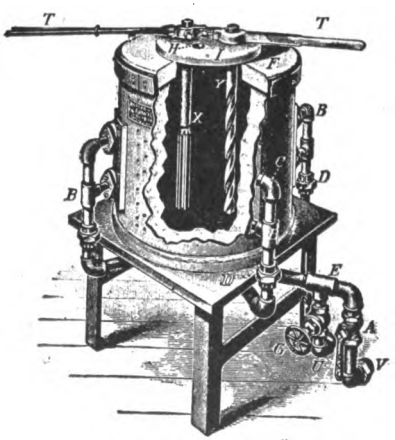


Fig. 22. Cylindrical Hardening Furnace for High-Speed Steel
Courtesy of American Gas Furnace Company, New York City

Milling-machine cutters, punch-press dies, and many other forms of tools should be heated in an oven furnace as shown in Fig. 23. Tools heated in this form of furnace should not be placed on the bottom but on a piece of fire brick, as shown.

As the temperature in a furnace being used for heating high-speed steel is extremely high, cold tools should not be placed directly in the furnace, but should be preheated in an open fire or in a slow fire of some kind, brought to a red heat, and then put into the special furnace. The sudden and unequal expansion of a piece of cold steel when placed in contact with a very high temperature, would cause it to crack in various parts.

Tempering for Delicate Tools. When taps, milling-machine cutters, and other tools having weak projecting portions are made from this steel, it is necessary to draw the temper in order to reduce the brittleness to a point where the tools will stand. To accomplish this, the surface is brightened and the temper drawn in the usual manner. The shanks of taps are plunged into red-hot lead, and allowed to remain there until they are red, when they are removed and buried in dry lime. The bodies of the taps are allowed to remain in the air.

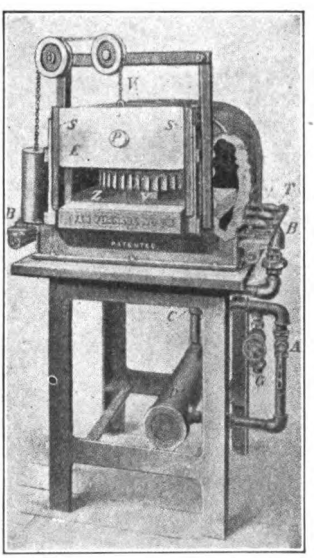


Fig. 23. Oven Furnace for Hardening Milling Cutters, Etc.
Courtesy of American Gas Furnace Company, New York City

Annealing. High-speed steel is annealed by being packed in an iron box with dry fire clay or a mixture of lime and powdered charcoal, or some material that will exclude the air. A cover is placed on the box and luted with fire clay, which is allowed to dry before the box is put into the furnace. It is necessary to heat this steel more than ordinary steel, and to maintain the high heat longer. Generally it is heated to a yellow heat and allowed to remain at this temperature for a length of time that varies with the size of the pieces. For small pieces, 2 or 3 hours will suffice, but for extremely large blocks the high temperature must be kept up for 12 or 15 hours—after they are heated through. The steel should be allowed to cool slowly.

Pack Hardening. In many shops difficulty is experienced in hardening such articles as milling-machine cutters, forming tools for screw machines, and similar tools made from high-speed steel. The work can be done with uniformly satisfactory results if the tools are

placed in an iron hardening box and surrounded with charred leather, a cover placed on the box and sealed, the whole being then put into the furnace and heated to a yellow heat. The articles should be kept in the furnace at this heat for several hours, the time depending on their sizes and shapes. For forming tools and milling-machine cutters of ordinary size 2 or 3 hours answer very well; smaller pieces should not be left in so long.

When the tools have been at the yellow heat for the proper length of time, they should be removed and plunged into a bath of raw linseed oil, and worked around in the oil until cool.

Merits of High-Speed Steel Tools. The results obtained from the use of high-speed steel tools are dependent in a very large measure on the way in which the tools are made and used. As they are principally valuable for roughing purposes, it is apparent that they should be made strong and of such shape as to bring as little strain as possible on the machine. When forging, the life of the tool should be considered, and a shape adopted that will permit a number of grindings. If the top of the cutting end of a tool is made of the same height as the top of the tool shank, it can be ground but a few times before it is necessary to dress it again, and the tool is consequently short-lived. If, however, the top of the cutting end of the tool is made higher than the top of the tool shank, it can be ground a number of times, so that the life of the tool is increased and the expense of forging proportionately lessened.

The use of high-speed steel for cutting tools has, as stated elsewhere, revolutionized machine-shop methods. Modern competition renders it necessary in many plants to reduce the cost of labor to the lowest possible limit, and the use of tools that allow extremely high speeds has done much toward making this reduction possible.

Shop System in Use of Steels. All steels are not equally good for all classes of work. Some work better on cast iron, while others are better adapted for steel cutting. In order to get the highest efficiency possible it is advisable, where several different metals are machined in quantities, to employ tools that are specially suited to the different kinds of work, each tool having the name of the steel from which it is made plainly stamped on it. However, when most of the material machined is cast iron, special tools for steel cutting need not be made as the tools used for cast iron will answer.

If several kinds of steel are used in a shop, each tool should be given a distinguishing mark, as one tool might be made from ordinary crucible steel, another from a steel containing a small amount of tungsten, and still another from high-speed steel. Tools made from each of these grades require different treatment and unless they are marked or a record of them kept, it is impossible after a time to distinguish between them.

Tungsten steels may be recognized, when grinding on an abrasive wheel, by the appearance of the spark, which will be blood-red in color and round in form; carbon steel, when ground, gives off a yellow spark which bursts in the air.

STANDARD TOOLS

DRILLS

The forms of drills commonly used in the machine shop are the flat drill, straightway drill, single-lip drill, and twist drill.

Flat Drills. Flat drills, intended for use in the engine lathe for chucking, are usually forged to shape in the forge shop. After center-

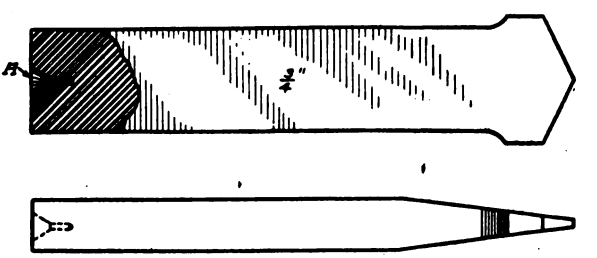


Fig. 24. Flat Drill for Chucking in Lathe

ing the end, which rests on the tail center of the lathe, the lips are ground to shape, and the drill is ready for use. A drill of this description is shown in Fig. 24.

If it is necessary to have the drill cut almost exactly to size, it should be forged somewhat wider than finish size, and the edges turned in the lathe, as in Fig. 25. The projection *A* must be left on the cutting end to provide a center for turning. If the drill is to be ground to size after hardening, the projection must be left on until

the grinding has been done, but ordinarily this class of drill is not intended to cut exactly enough to require grinding to size.

Filing. If the edges of the drill are not to be ground to size, they should be drawfiled a small amount to avoid binding. The filing should not come within $\frac{1}{64}$ inch of the edge, and should be only a small amount—.003 or .004 inch will be found sufficient; if given too much relief, the drill will jump and chatter. The shank should be somewhat smaller than the cutting end—$\frac{1}{32}$ to $\frac{1}{16}$ inch—in order not to touch the walls of a hole drilled deep enough for the shank to

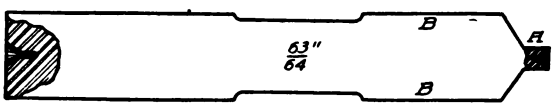


Fig. 25. Making Flat Drill for Chucking

enter. The center in the shank end should be large, to insure a good bearing on the tail center of the lathe, as shown at *A*, Fig. 24.

Hardening. In hardening, the drill should be heated a low red to a point above the cutting end, preferably about one-half the length of the portion turned smaller than the ends. When dipped into the bath, it should be plunged about one inch above the cutting end. To insure good results, it should be worked up and down and around in the bath, which may be either water or brine. The temper should be drawn to a brown color.

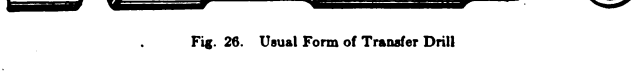


Fig. 26. Usual Form of Transfer Drill

When a flat drill is intended for use in a drill press, the shank is left round, in order that it may be held in a chuck or collet.

Transfer Drill. Another form of flat drill, termed a transfer drill, is very useful when a small hole is to be transferred from a larger. The shank *C*, Fig. 26, may be made of any convenient size; the portion *B* is of the size of the larger hole, while *A* is of the size of the hole to be transferred, and is a short flat drill.

If a lathe is used having draw-in split chucks, the drill may be made from drill rod which should be enough larger than finish size

to allow B to be turned to insure its running true with A; the cutting part A may be milled or filed to thickness. The cutting lips are then backed off, and the drill hardened high enough up so that A

Fig. 27. Straightway or Straight Fluted Drill
Courtesy of Union Twist Drill Company, Athol, Massachusetts

and B are hard, as the portion A does the cutting, while B, being a running fit in a hole, is likely to rough if it is soft.

To harden, the drill should be heated in a tube and dipped in water or brine, and worked up and down, to avoid soft spots caused by steam keeping the water from the metal, which sometimes happens when a piece has different sizes close together. The cutting portion A should be drawn to a deep straw color; B should be left as hard as possible, to resist wear.

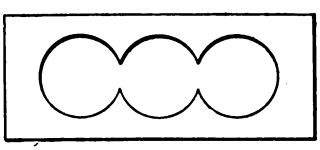


Fig. 28. Stock Drilled with Straightway Drill

Straightway or Straight Fluted Drills. These drills have the flutes cut parallel to a plane passing through the axis of the drill, as shown in Fig. 27. They are used in drilling brass, iron, and steel, when the holes break into one another, as shown in Fig. 28.

The smaller sizes may be made of drill rod. After cutting to length, the blank may be put in a chuck in the lathe and the end pointed to the proper cutting angle. When milling the flute, the shank may be held in the chuck on the end of the spiral-head spindle. The head should be set at an angle that makes the flute deeper at the cutting end of the drill than at the shank end; this causes an increase of thickness at the shank and makes the drill stronger than if the flute were of uniform depth throughout. The milling cutter should be of a shape that will make the cutting face of the drill a straight line when the drill is ground to the proper cutting angle. The

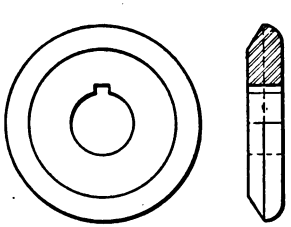


Fig. 29. Cutter for Straightway Drill

corner should be somewhat rounded. The general shape of the cutter is shown in Fig. 29.

Single-Lip Drill. For certain classes of work the single-lip drill is very useful. Having but one cutting edge, its action is similar to

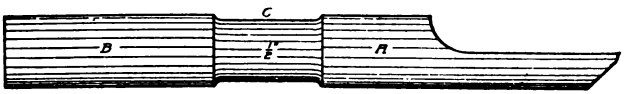


Fig. 30. Single-Lip Drill Used with Bushings

that of a boring tool used for inside turning in the engine lathe. The body of the drill being the size of the hole drilled insures the cutting of a straight hole, even in drilling work partly cut away, or castings having blowholes or similar imperfections. This drill does not cut as rapidly as the other forms, and consequently is not used where a twist drill would do satisfactory work.

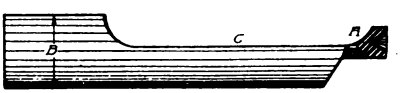


Fig. 31. Method of Making Single-Lip Drill

Fig. 30 shows a form of single-lip drill to be used with a bushing. The steel should be somewhat larger than finish size, in order that the decarbonized surface may be removed; the cutting end *A* and the shank *B* should be turned from .014 to .020 inch larger than the finish diameter to allow for grinding after the drill is hardened. The portion *C* should be turned to finish size and stamped. In order that the drill may be ground to size after it is hardened, it will be necessary to face the end back, leaving the projection containing the center as shown at *A*, Fig. 31. The cutting end should be milled to exactly one-half the diameter of *B*. After milling, the face *C* should be drawfiled until it is flat and smooth.

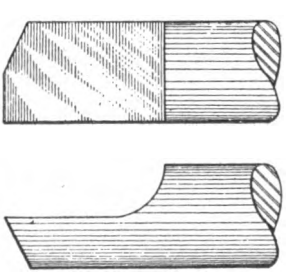


Fig. 32. Method of Grinding Single-Lip Drill

Hardening. When hardening, the drill should be slowly heated to a low red, a trifle higher than the portion that is to be cutting size;

it should then be plunged into a bath of warm water or warm brine in order to avoid so far as possible any tendency to springing or cracking in the projection *A*. The tendency to crack is due to its peculiar shape and the difference in its size and that of the drill. After hardening, it may be drawn to a straw color.

Grinding. It is advisable to grind the shank first, in order that the machine may be adjusted to work straight. After grinding the

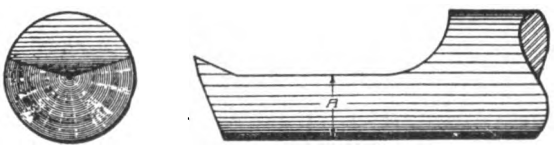


Fig. 33. Rake of Cutting Face of Drill for Iron and Steel

shank and cutting end to size, the projection *A* may be ground off, and the cutting end given the required shape, as shown in Fig. 32.

Giving Rake to Cutting Face. When a single-lip drill is to be used on iron and steel, and not upon brass, it may be made to cut more freely by giving the cutting face a rake, as shown in Fig. 33. This is done by milling the portion *A* to the proper dimension, which is one-half the diameter of the blank. The end and sides of the drill are now coated with the blue vitriol solution and the desired shape

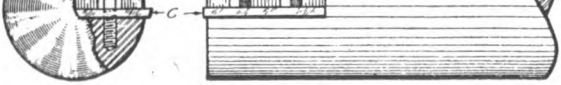


Fig. 34. Single-Lip Drill with Inserted Cutter

marked out, after which the tool is placed in the milling-machine vise at the proper angle, and the required amount of rake obtained by means of small end-cutters. After giving the necessary end clearance, as shown in the two views of Fig. 33, the drill is ready for hardening.

Inserted Cutter. In order to adjust a drill of this kind to compensate for wear, it may be made as shown in Fig. 34, in which one-quarter of the circumference plus the thickness of the cutter to be

used, is cut away at *A* and a blade or cutter fastened in position, the top face of which should be radial. To compensate for wear, pieces of paper or thin sheet metal may be inserted under the blade. When cutting away the portion *A*, three holes may be drilled, as shown in Fig. 35.

If square corners are desired, care should be taken that the holes are located so that they will machine out when milling to the proper dimensions. After drilling, the body of the drill should be placed in a vise in the shaper, and by the use of the cutting-off tool (parting tool) the portion removed; but as it would be impossible to cut to finish dimensions, it will be necessary to finish with small end milling cutters, holding the tool in the chuck on the spindle of the spiral head. After machining one surface, the spindle may be revolved one-quarter turn and the other surface machined; this

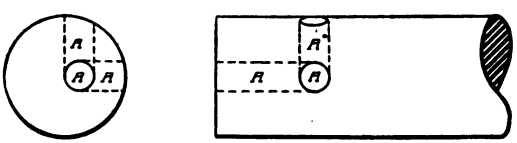


Fig. 35. Diagram Showing Method of Cutting Out Quadrant for Inserted Cutter

insures square corners, and two surfaces at right angles to each other. The surface on which the cutter is to rest should be cut below the line of the center, so that the top edge of the cutter may be radial—that is, it should be cut the thickness of the cutter below a line passing through the center, Fig. 34.

The cutter should be made of tool steel and two holes drilled for the fastening screws. When the cutter has been fastened in position, it may be turned to the proper diameter by running the body of the tool in the steady rest of the lathe. Care should be used not to cut into the body or holder. After turning to size and facing the end square, the cutter may be removed from the holder, and necessary clearance given the end by filing; the outer edge may be drawfiled in order to smooth it, and a slight clearance given to prevent binding. This is done by removing a trifle more stock at the bottom than at the top edge. To harden, it should be heated to a low red heat and dipped in lukewarm water; the temper should be drawn to a straw color.

Twist Drills. It is, in general, cheaper and more satisfactory to buy twist drills than to attempt their manufacture in the ordinary machine shop; but at times some emergency may call for a special size or length of drill which it will be necessary to make.

For the smaller sizes, it is best to use commercial drill rod. For drills larger than ½-inch diameter, select larger stock and turn it to

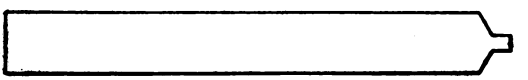


Fig. 36. Blank for Twist Drill

the desired size. In the case of the latter drills, if true holes of the size of the drill are required, it is advisable to turn them .010 to .015 inch larger than finish size, and grind to size after hardening. A projection, Fig. 36, containing the center, should be left on the cutting end of the drill until the grinding has been done. After cutting the flutes and grinding the drill, the projection may be ground off and the cutting lips ground to the proper shape, as shown in Fig. 37.

When making drills of the smaller sizes from drill rod, the blanks may be cut and pointed to the proper angle on the cutting end; this may be done in the lathe, the blank being held in a chuck. The proper angle is 59 degrees from one side of the blank. When milling the flutes of a twist drill on a universal milling machine, the shank of the drill, if straight, may be held in a chuck or collet of the right size, and, if very long, may be allowed to pass through the spiral head.

Fig. 37. Finished Twist Drill
Courtesy of Union Twist Drill Company, Athol, Massachusetts

Milling Flutes. The accompanying explanation and table are taken from the Brown and Sharpe Manufacturing Company's book, "Construction and Use of Milling Machines", and are intended to use with the cutters manufactured by them for making the flutes in twist drills.

The cutter is placed on the arbor directly over the center of the drill, and the bed is set at the angle of the spiral, as given in Table II.

TABLE II

Data for Cutting Twist Drills

Diameter of Drill (in.)	Thickness of Cutter (in.)	Pitch (in.)	Gear on Worm	First Gear on Stud	Second Gear on Stud	Gear on Screw	Angle of Spiral
1/16	06	67	24	86	24	100	16° 20′
1/8	08	1 12	24	86	40	100	19° 20′
3/16	11	1 67	24	64	32	72	19° 25′
1/4	15	1 94	32	64	28	72	21°
5/16	19	2 92	24	64	56	72	20°
3/8	23	3 24	40	48	28	72	21°
7/16	27	3 89	56	48	24	72	20° 10′
1/2	31	4 17	40	72	48	64	20° 30′
9/16	35	4 86	40	64	56	72	20°
5/8	39	5 33	48	40	32	72	20° 12′
11/16	44	6 12	56	40	28	64	19° 30′
3/4	50	6 48	56	48	40	72	20°
13/16	56	7 29	56	48	40	64	19° 20′
7/8	62	7 62	64	48	32	56	19° 50′
15/16	70	8 33	48	32	40	72	19° 30′
1	77	8 95	86	48	28	56	19° 20′

The depth of groove in a twist drill diminishes as it approaches the shank, in order to obtain increased strength at the place where the drill is otherwise

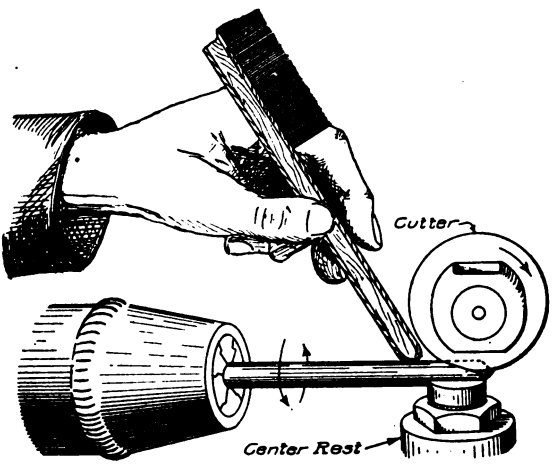


Fig. 38. Supporting Twist Drill for Grinding

generally broken. The variation in depth depends on the desired strength or the use of the drill. To obtain the necessary variation of depth, the spindle of

the spiral head is elevated somewhat, depending on the length of the flute to be cut; when less than 2 inches in length, the angle should be ¼ degree; 5 inches and over in length, 1 degree. Usually this will be found satisfactory, but for extremely long drills the elevation must exceed these amounts. The outer end of the drill must be supported as shown in Fig. 38; and when small, should be pressed down firmly until the cutter has passed over the end.

It is somewhat better to use left-handed cutters, so that the cut may begin at the shank end, in order to lessen the tendency to lift the drill blank from the rest. When large drills are held by the centers, the head should be depressed in order to decrease the depth of the groove as it approaches the shank.

Backing Off Rear of Lip. Another very important operation on the twist drill is that of backing off the rear of the lip, to give it the necessary clearance. In Fig. 39 the bed is turned to about ¼ degree, as for cutting a right-hand spiral; but as the angle depends

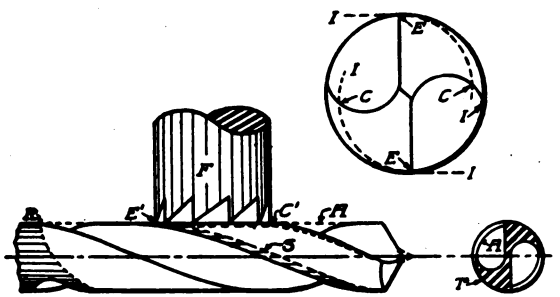


Fig. 39. "Backing Off" a Twist Drill

on several conditions, it will be necessary to determine what the effect will be under different circumstances. A study of the figure will be sufficient for this by assuming the effect of different angles, mills, and the pitches of spirals. The object of placing the bed at an angle is to cause the mill F to cut into the lip at C' and just touch the surface at E'. The line R being parallel to the face of the mill, the angular deviation of the bed in comparison with the side of the drill is clearly shown at A.

While the drill has a positive traversing and relative movement, the edge of the mill at C' must always touch the lip a given distance from the front edge, this being the vanishing point; the other surface, forming the real diameter of the drill, is beyond the reach of the cutter, and is left to guide and steady it while in use. The point E,

as shown in the enlarged view, Fig. 39, shows where the cutting commences, and its increase until it reaches a maximum depth at *C*, where it may be increased or diminished according to the angle employed in the operation, the line of cutter action being represented by *II*.

Before backing off, the surface of the smaller drills in particular should be oxidized by heating until it assumes some distinct color to show clearly the action of the mill on the lip of the drill, for, when satisfactory, a uniform streak of oxidized surface, from the front edge of the lip back, is left untouched by the mill, as represented in the cut at *E*.

If the drills are to be ground without being centered, pointed projections with a 60-degree angle may be made on the ends, as shown in Fig. 39; these projections may be run in female centers in the grinding machine. In grinding, if the drills are tapered back about .003 inch in 6 inches, it will be found that the clearance thus obtained will cause them to run much better.

Hardening. Twist drills are hardened by special processes which, generally speaking, are not understood outside the shop where the drills are made. Very good results, however, may be obtained if the drills are heated somewhat and dipped into a solution of the following:

Pulverized charred leather	1 pound
Fine family flour	1½ pounds
Fine table salt	2 pounds

The charred leather should be ground or pounded until fine enough to pass through a No. 45 sieve. The three ingredients are thoroughly mixed while in the dry state, and water is then added, *slowly*, to prevent lumps, until the mixture formed has the consistency of ordinary varnish.

After the drill has been dipped in the mixture it should be laid in a warm place to dry; when thoroughly dried it should be heated in a tube, or preferably in a crucible of red-hot lead, until it is a low red, and then plunged into a bath of lukewarm water or brine; small drills may be dipped in a bath of oil. The drill must not be put in red-hot lead until the coating is thoroughly dried, as the moisture may cause minute particles of lead to fly in all directions, endangering the eyes of the operator. After hardening, the temper should

be drawn to a full straw color. If several drills are hardened at one time, the temper may be drawn by placing them in a kettle of oil over a fire, gaging the amount of heat by a thermometer, as explained in the section on the tempering of tool steel.

A bath that insures excellent results when drills and similar articles are hardened, is shown in Fig. 79. This bath has perforated pipes extending up the sides, as shown. The water from the perforations is projected against the drill and to the bottoms of the flutes, so that uniform results are assured.

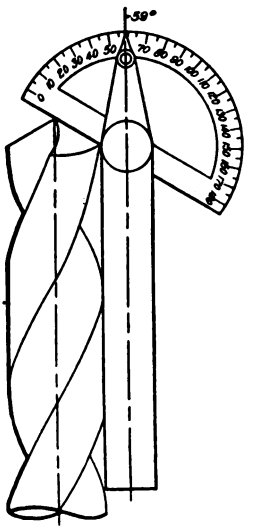


Fig. 40. Checking the Proper Angle for Twist Drill

Grinding. Although most shops are provided with a special machine for grinding twist drills, yet at times it is necessary to grind such tools by hand, and every workman should practice until he is able to do this properly without the use of a special machine. The cutting edges must make a proper and uniform angle with the longitudinal axis of the drill; they must be equal in length, and the lips of the drill sufficiently backed off for clearance; otherwise they will not cut easily, or if they do cut, they will make a hole larger than the size of the drill.

Drills properly made have their cutting edges straight when ground to a proper angle, which is 59 degrees, Fig. 40. Grinding to an angle less than 59 degrees leaves the lip hooking, which is likely to produce a crooked and irregular hole.

A very satisfactory form of an angle-gage for this work is shown in Fig. 41. The graduations on the upper part of the gage show when the lips are ground to an equal length, which is essential if the drill is to cut the proper size. As the operator becomes experienced, he can gage the angle and length of lips very accurately by the eye, but until he has had the necessary experience, it is advisable to use some form of gage.

Drills for Deep Holes. A good drill for use in drilling deep holes, in such work as gun barrels, machine spindles, and similar

pieces, is shown in Fig. 42. This tool was brought out by the Pratt and Whitney Company, of Hartford, Connecticut, and is used in connection with their gun-barrel drilling machines. It is especially valuable because it produces a straight, true hole. It has but one cutting lip as will be noticed by referring to the end view of the tool. In milling the groove that forms the cutting edge, the surface *b*, is exactly on the center. An oil groove *c* is provided, as shown, through which oil may be forced to the cutting edge by means of a powerful pump. The oil is under pressure varying, according to the diameter of the drill, from 150 to 200 pounds per square inch. After lubricating the cutting edge it carries the chips back through the chip groove and deposits them outside of the drilled hole. For drilling very large holes the cutting edge of the drill is usually made with a series of step-like cuts, as shown in Fig. 43, which break the chips so that they can be carried back through the chip groove.

Fig. 41. Fixed Angle Gage for Twist Drill

In sharpening the drill, the point is not produced in the center, but at one side, as shown; this is one of the reasons for the drill's cutting true, as the projection *A* in work acts as a support. When using this style of drill it is customary to run at high speed and employ a fine feed.

Because of the position of the point it is necessary to run the drill, when starting, through a bushing, or V-guide, as otherwise it

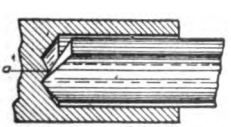


Fig. 42. Special Drill for Drilling Deep Holes

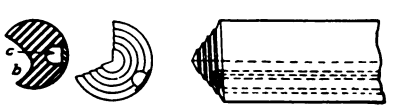


Fig. 43. Form of Drill for Very Large Holes

would not be possible to produce a hole concentric with the circumference.

Use of High-Speed Steel. High-speed steel is used very extensively in making drills, especially of the larger sizes. They can be run at very much greater speed than those made from carbon steel, and used for drilling harder materials. At times trouble is experienced when using high-speed drills for very deep vertical holes; but the trouble may be obviated by forcing a stream of oil down into the hole with sufficient force to cause the chips to come to the surface of the work, thus giving the oil free access to the cutting lips.

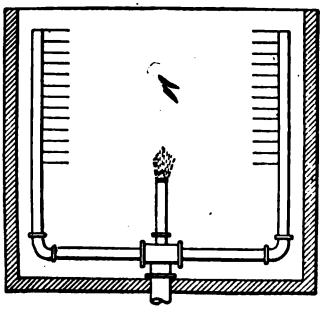


Fig. 44. Section of Oil Bath with Perforated Side Pipes

When hardening drills made from high-speed steel, first pre-heat in a slow fire to a low red, then suspend in a furnace of the design shown in Fig. 22 and heat to a uniform temperature of 2100° F., finally immersing in a bath of cottonseed oil. If possible, use a bath having perforated pipes up the

Fig. 45. Twist Drill Formed from Flat Stock

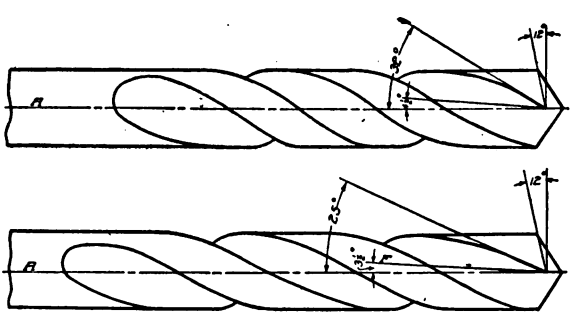


Fig. 46. Twist Drill with Angle of Spiral Changed for High-Speed Work

sides, as shown in Fig. 44, so that the oil may get to the bottom of the flutes and harden all portions of the drill. In order that

the drill may not be brittle after the hardening operation, the temper should be drawn to 460° F.

Tools for Rapid Drilling. For rapid drilling there are various styles of twist drills. Fig. 45 shows one made from flat stock twisted to form the flutes, which is especially satisfactory for certain classes of work. Fig. 46 shows the regular design except that the angle or spiral is 32 degrees instead of 25 degrees. The quick twist permits more rapid cutting and greater production by the operator.

REAMERS

A reamer is a tool that makes a smooth, accurate hole. In many cases, however, reamers are used to enlarge cored holes, or

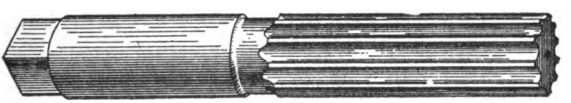


Fig. 47. Solid Reamer

holes already drilled, without particular reference to the exact size or condition of the hole. Reamers may be classified according to shape as follows: straight reamers, taper reamers, and formed reamers. Reamers are made solid, adjustable, and with inserted blades.

Solid reamers, Fig. 47, are so called because the cutting teeth and head are made from one piece; they have no means of adjustment as to size. The cutting teeth of the inserted-blade reamers are made from separate pieces of steel and inserted in the head, as shown in Fig. 48. The adjustable reamer may be made with inserted

Fig. 48. Reamer with Inserted Blades
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

teeth, or with cutting teeth solid with the head; but in either case it has some means of adjusting the size.

STRAIGHT REAMERS

Under this heading the following kinds of reamers are to be found: fluted hand reamers, fluted chucking reamers, rose reamers, single-lip reamers, and three- and four-lipped roughing reamers.

Fluted Hand Reamers. This reamer is made straight on the cutting lips, with the exception of a short distance at the end, *A*, Fig. 49, which is slightly tapered in order that the reamer may enter

Fig. 49. Proper Proportions for Fluted Hand Reamer

the hole. In making such reamers, use steel from $\frac{1}{32}$ inch to $\frac{1}{8}$ inch above finish size. Turn a chip off the outside surface to a depth of $\frac{1}{32}$ inch, and anneal; then turn *A* and *B*, to sizes .010 to .015 inch larger than finish size; turn *C* to finish size; mill the end *D* square for a wrench. The reamer is now ready to have the flutes cut.

Number of Cutting Edges. Fluted reamers designed to remove but a small amount of stock, and intended to cut holes to an accurate size, are rarely given less than six flutes. Below are given the number of cutting edges advisable for solid reamers whose flutes are milled by cutters made to give the proper shape:

Reamers	$\frac{1}{8}$″	to $\frac{7}{16}$″	in diameter should have 6 teeth
Reamers	$\frac{1}{2}$″	to $\frac{11}{16}$″	in diameter should have from 6 to 8 teeth
Reamers	$\frac{3}{4}$″	to 1″	in diameter should have 8 teeth
Reamers	$1\frac{1}{16}$″	to $1\frac{1}{2}$″	in diameter should have 10 teeth
Reamers	$1\frac{9}{16}$″	to $2\frac{1}{8}$″	in diameter should have 12 teeth
Reamers	$2\frac{1}{4}$″	to 3″	in diameter should have 14 teeth

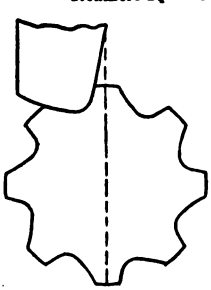


Fig. 50. Shape of Cutter for Reamer

Formerly it was considered necessary to have an odd number of cutting edges; but an even number, if unevenly spaced, will be as satisfactory. The chief objections to an odd number are the difficulty experienced in calipering, unless a ring gage is used, and the great cost of grinding.

Fig. 50 shows a form of cutter that makes a strong reamer tooth and allows the chips to be removed very readily. These cut the tooth ahead of the center, and should be given a negative rake of about 5 degrees. In general, a reamer will cut more smoothly if the tooth has a slight negative rake, as it then takes a scraping cut.

Depth of Cut. With this form of flute, the depth of cut must be so gaged that the land will be about $\frac{1}{8}$ the average distance from one cutting edge to the other; if cut deeper, the teeth will be weak and have a tendency to spring; if not so deep, there will not be room for the removal of the chips. Below are tabulated the number of cutters, Fig. 50, for various sizes of reamers.

No. 1 cutter cuts reamers from	$\frac{1}{4}$″	to	$\frac{7}{16}$″ diameter
No. 2 cutter cuts reamers from	$\frac{1}{2}$″	to	$\frac{7}{16}$″ diameter
No. 3 cutter cuts reamers from	$\frac{3}{4}$″	to	$\frac{7}{16}$″ diameter
No. 4 cutter cuts reamers from	$\frac{1}{2}$″	to	$\frac{11}{16}$″ diameter
No. 5 cutter cuts reamers from	$\frac{3}{4}$″	to	1″ diameter
No. 6 cutter cuts reamers from	$1\frac{1}{16}$″	to	$1\frac{1}{2}$″ diameter
No. 7 cutter cuts reamers from	$1\frac{11}{16}$″	to	$2\frac{1}{2}$″ diameter
No. 8 cutter cuts reamers from	$2\frac{1}{2}$″	to	3″ diameter

Spacing of Teeth. In order that reamers may be calipered readily when grinding, if the teeth have been unevenly spaced, the teeth must be diametrically opposite each other; the unevenness in spacing must be between adjoining teeth. This is done by cutting one tooth, then turning the spiral head of the milling machine half-way round, by giving the index pin twenty revolutions, and then cutting the opposite tooth. When the flutes are cut in pairs, the number of times the cutter must be set for depth of cut is reduced one-half. Fig. 51 shows an end view of a reamer having the first pair of flutes cut as described. The irregularity of spacing is obtained by moving the index pin a different number of holes for each adjoining pair of flutes. This irregularity need not be great, a variation of 2, 3, or 4 degrees from an angle corresponding to regular spacing, is generally regarded as good practice.

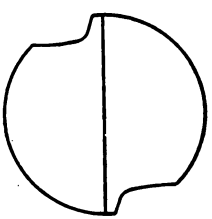


Fig. 51. Reamer with First Pair of Flutes Cut

Finishing Processes. *Hardening.* In order that a reamer may not spring when hardened, great care should be exercised in heating. If a muffle furnace is at hand, a uniform heat can be obtained. If heated in a blacksmith's forge, the reamer should be placed in a tube to prevent the fire from coming in contact with the steel, and should be turned frequently to secure uniform results. In cooling, it should be held in a vertical position to avoid springing, and worked up and down in the bath.

If the reamer is one inch in diameter or larger, it should be removed from the hardening bath when it stops "singing", and plunged into oil, and allowed to remain until cold. The temper may be drawn to a light straw color. If reamers are hardened by the pack-hardening process, the danger of springing is greatly reduced.

Straightening. The straightening should be done before drawing the temper. When drawing the temper, the heat should be applied evenly, or the piece will spring from uneven heating.

If a reamer springs while hardening and tempering, it may be straightened by the following method:

Place the reamer between the centers of the lathe; fasten a tool, or a piece of iron or steel having a square end, in the tool post, Fig. 52,

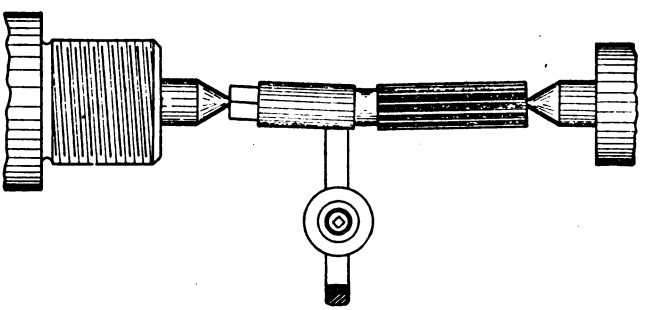


Fig. 52. Diagram Showing Method of Straightening a Bent Reamer

placing the square end against the reamer at the point of greatest curvature. The surface of the reamer should be covered with a thin coating of sperm or lard oil. With a spirit lamp, a plumber's hand-torch, or a bunsen burner, heat the reamer evenly until the oil commences to smoke. Pressure may now be applied by means of the cross-feed screw, slowly forcing the reamer over until it is bent a trifle the other way. It should be cooled evenly while in this position, after which the pressure may be relieved and the reamer tested for truth. If it does not run true, the operation should be repeated This method of straightening is equally effective when applied to other classes of work.

Grinding. Before grinding a reamer, be sure that the centers of the grinding machine are in good shape; then clean the centers of

the reamers. The reamer should first be ground to run true. It may be ground to within .001 or .002 inch of finish size, larger reamers having the larger margin. In backing off a reamer tooth for clearance, use an emery wheel of as large diameter as can be used without striking the cutting edge of the next tooth. The correct clearance is given by a finger which can be adjusted. Fig. 53 shows an end view of a reamer being ground for clearance, together with the finger and the emery wheel. The emery wheel should run in the direction indicated by the arrow, in order that the pressure of the wheel will tend to force the reamer tooth down on the finger *B*. To give clearance, the finger is adjusted so that the cutting edge is below the line of centers, as shown. The lower the finger, the greater the amount of clearance. Unless a free-cutting wheel, without glaze is used, the temper will be drawn, and the reamer rendered worthless. To avoid softening the teeth, the stock must be removed by a succession of light cuts going entirely around the reamer each time the adjustment is changed.

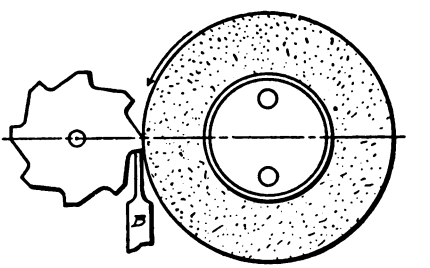


Fig. 53. Diagram Showing Method of Grinding Reamer for Clearance

A reamer will soon lose its size if the clearance is ground to the edge of the teeth; consequently it is best to grind to within from .01 to .015 inch of the edge, according to the size. The reamer is then brought to an edge and to the desired size by oil-stoning. To do satisfactory work, the stone should be free-cutting; a stone of medium grade is best for removing the stock, and a fine stone for finishing the cutting edge. An oil-stone should *not* be used dry; the face must be kept free from glaze. If there are deep depressions or marks in the stone it should be faced off on a wet grindstone.

Fluted Chucking Reamers. The same general instructions given for making fluted hand reamers are applicable to this form, except that the shank may be finished to size before the reamer is hardened, unless the shank is to fit a collet or is to be held in a chuck.

The regular jobbing reamer used in the lathe is shown in Fig. 54; the form for the chucking lathe or drill press, where the shank is held in a collet or a chuck, is shown in Fig. 55. When making the latter style of reamer, *B* may be left .010 to .015 inch above size to allow for grinding. The portion *C* may be finished to size, and the dimension of the cutting part of the reamer stamped on it as shown; if the reamer is made for special work and is to be used on no other, the name of the piece or operation for which it is intended should also be stamped.

On account of the uncertainty of a reamer cutting exactly to size when used in a lathe, chucking reamers are frequently made

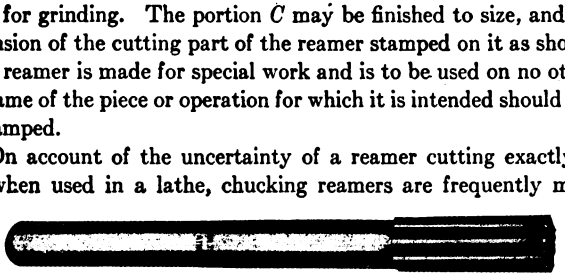


Fig. 54. Rose Fluted Chucking Reamer
Courtesy of Union Twist Drill Company, Athol, Massachusetts

somewhat under size. Standard hand reamers are used for finishing. The amount of stock left for the hand reamer varies. Some toolmakers consider .005 inch the proper amount for all reamers up to 3 inches in diameter; while others think that for 1 inch or less diameter, .004 inch is right, and that for sizes from $1\frac{1}{16}$ inches to 2 inches,

Fig. 55. Chucking Reamer with Straight Shank for Screw or Chucking Machines

.007 inch should be allowed. For reamers larger than 2 inches in diameter, an allowance of .010 inch should be made. The exact amount necessary for finishing with hand reamers depends on the nature of the work and the stock operated on. Fluted chucking reamers are made with either straight or spiral flutes.

When a reamer is used in a screw machine or a turret lathe, on work where accuracy and straightness of hole are essential, it should be held in some form of special holder, which allows it to locate itself properly as to alignment. These holders will be described later.

Rose Reamers. This form of reamer has its cutting edges only on the end, the grooves being cut the entire length of body to reduce

the amount of frictional bearing surface and to furnish a channel to conduct the lubricant to the cutting lips. In case there are blow-holes or other imperfections in the material being operated on, this reamer will cut a more nearly parallel hole than the fluted chucking reamer.

Fig. 56 shows the ordinary form of rose chucking reamer. The shank is turned to finish size; if it is to fit a holder, it is left slightly larger and turned or ground to size after hardening. The body is turned .015 to .020 inch above finish size and the flutes cut; the size is stamped as shown, and the reamer hardened a little above the body. It is customary, when grinding a rose reamer, to make it a

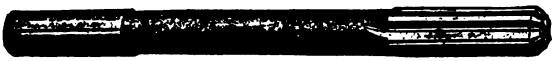


Fig. 56. Rose Chucking Reamer with Straight Shank for Screw or Chucking Machines
Courtesy of Union Twist Drill Company, Athol, Massachusetts

trifle smaller on the end of the body next to the shank—a taper of $\frac{1}{1000}$ inch in the length of the cutting part gives good results.

Small rose reamers can be made of drill rod, which runs very true to size, if ordered by the decimal equivalent rather than by the

Fig. 57. Small Reamer "Necked Down"

drill gage number, or in terms of common fractions. For instance, if drill rod is wanted of a size corresponding to No. 1 Brown and Sharpe drill gage, the size will be much more accurate if ordered as .228 inch diameter, rather than by the gage.

The drill rod may be sawed to length, put in the lathe chuck, and cornered for the cutting lips. When making small reamers that are not to be ground to size after hardening, it is advisable to "neck them down" back of the cutting edge, as shown in Fig. 57. The drill rod often swells or expands at a point where the hardening ends; and by necking down and hardening into the necking, this difficulty is overcome.

Making Flutes. Small rose reamers may be given three cutting edges. The flutes may be filed with a three-square or a round-edge file. If a three-square file is used, a groove of the form shown in Fig. 57 may be made. This has a tendency to push the chips ahead when cutting, while a groove filed with a round-edge file, if it is of a

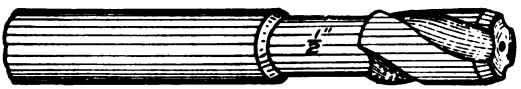


Fig. 58. Reamer with Right-Hand Helix

spiral form, will draw the chips back into the flute, provided it is a right-hand helix, as shown in Fig. 58.

Grinding. Rose reamers intended for reaming holes of exact size must be ground to correct dimensions after hardening, but small reamers intended for reaming holes where exactness of size is not essential may be made to size before hardening, and the cutting edges backed off with a file for clearance. If reamers are ground on the circumference for size, the lips or cutting edges should be given clearance by grinding. After grinding, the corners of the cutting edges next to the body of the reamer, as shown at the right end of Fig. 56, should be rounded by oil-stoning.

Single-Lipped Reamers. A single-lipped reamer is very useful for reaming a straight hole. When the nature of the hole or the condition of the stock would cause the ordinary forms to run, the single-lipped reamer will cut a straight hole if started right. Having but one cutting lip, its action is similar to that of a boring tool used for inter-

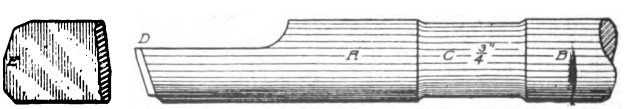


Fig. 59. Single-Lipped Reamer

nal turning in the lathe, and as a large proportion of the body of the reamer acts as a guide, it must cut a straight hole. Fig. 59 shows two views of this form of reamer.

Steel for this tool should be sufficiently large to allow the decarbonized surface to be entirely removed. After a roughing chip has

been taken—leaving the piece about $\frac{1}{16}$ inch above finish size—the stock should be annealed, and the portions *A* and *B* turned to a size that allows for grinding. *C* may be finished to dimensions given, and the size stamped as shown.

Milling. The reamer is now ready for milling. This should be done with the reamer in the centers in the milling machine, using a shank mill or a small milling cutter on an arbor. The depth of the cut should be about one-third the diameter of the reamer; for large reamers, it may be somewhat deeper. After the milling, the face may be smoothed with a fine file, and the end and cutting lip backed off for clearance, as shown in Fig. 59 at *D* and *E*.

Hardening. When hardening, the end *A* should be heated to a low red and dipped in the bath about one-half an inch up on the necked portion *C*. The temper may be drawn to a light straw. *A* and *B* are now ready for grinding. If the grinder has no provision for the running of water on the work, care should be used not to heat the reamer, as it is likely to spring.

Three- and Four-Lipped Roughing Reamers. These are used to advantage in chucking machines, for enlarging cored holes or holes

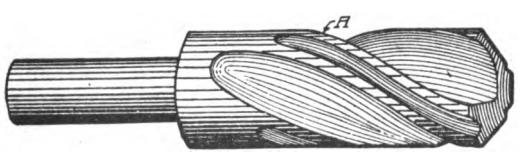


Fig. 60. Three-Lipped Reamer

that have been drilled smaller than the required size. Large holes in solid stock are often made below size, as most manufacturers consider it more economical to use a smaller drill and a roughing reamer to bring them to proper size for the final reamer. Fig. 60 shows a reamer of this description.

The instructions already given for making the various reamers may be followed for this form, with the exception of cutting the grooves, which should be of a sufficient size to hold the chips. The small groove cut in the center of the lands is to feed oil to the cutting edges when cutting steel. When cast iron is the material to be operated on, the grooves are cut straight and the oil groove omitted.

If a finish reamer is to be used in sizing the holes, it is customary to make the roughing reamer $\frac{1}{64}$ inch smaller than finish size. On account of the rough usage, great care should be exercised in hardening. While satisfactory results may be obtained by heating them to a low red, plunging them into a bath of brine, and drawing the temper to a light straw, the tools will do a great deal more if they are pack hardened.

Inserted-Blade Reamers. The particular advantage of solid reamers with inserted teeth is that, when worn, new blades may be

Fig. 61. Inserted-Blade Reamer with Section Showing Method of Inserting Blades

put in at a cost much less than that of a new solid reamer. Inserted-blade reamers are usually made in such a manner that the size can be altered; in such cases they are termed *expanding reamers*. A simple form is shown in Fig. 61. The slots for the blades are milled somewhat deeper at the front end than at the end toward the shank; they are also somewhat wider at the bottom than at the top. The first is accomplished by depressing the spiral head a trifle; while the latter is done by first milling the slots with a cutter a little narrower than the top of the slot wanted, then turning the spiral head enough to produce the desired angle on one side of the slot, as shown at *A* in Fig. 62. The object in making the slot deeper at the front end is that the blades, as they become dulled, and consequently cut small, may be driven farther into the body. As the slot is shallower, the blade is forced out as it advances, thus increasing its diameter; it may then be sharpened by grinding to size. The side of the slot is cut at an angle to hold the blade solidly and prevent any tendency it might have to draw away from its seating when the reamer is cutting. The body of the reamer is not hardened; the blades are machined to size, hardened, driven into place, and ground to size. If the reamer is of the form known as fluted reamer, the teeth may be backed off for clearance as already described.

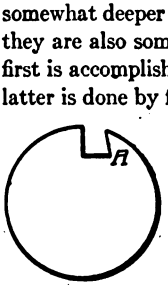


Fig. 62. Form of Slot for Inserted Blade

Adjustable Reamers. These are made in a form that allows them to be adjusted to a varying size of parts of machines where interchangeability is not essential. Fig. 63 shows the cheapest type of adjustable reamer, one sometimes objected to because it does

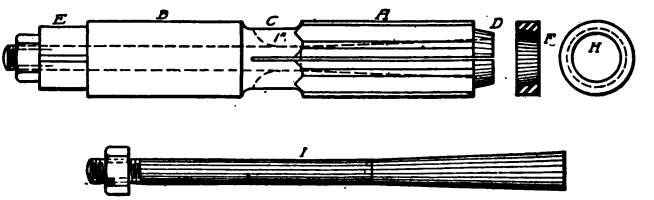


Fig. 63. Adjustable Reamer

not expand or contract uniformly its entire length; for ordinary work, however, it is very satisfactory, if used for a limited range of sizes.

Stock should be selected at least $\frac{3}{32}$ inch larger than finish size. After carefully centering and squaring the ends, a chip should be turned the entire length of the piece, which is then drilled, and the taper hole reamed for the expansion plug. When drilling the outer end, the blank should run in the steady rest; the hole in the shank end should be drilled to the proper depth with a tool $\frac{1}{32}$ inch larger than the straight stem of the expansion plug. The end should be chamfered to a 60-degree angle, to run on the lathe center when turning and grinding. The piece may be reversed and the opposite end drilled and reamed with a taper reamer; this end should be

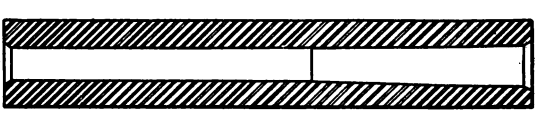


Fig. 64. Blank for Adjustable Reamer Drilled and Reamed

chamfered also to a 60-degree angle. Fig. 64 shows a sectional view of the blank drilled and reamed and the ends of the hole beveled.

The reamer should now be turned .020 to .025 inch above finish sizes on *A* and *B*, while *C* and *D*, Fig. 63, are turned to finish sizes, and the size stamped at *C*. The end *E* should be milled square for a wrench, the grooves milled, and the reamer split, in order that the

TABLE III

Data of Shell Reamers

Diameter (in.)	Length (in.)	Size of Hole (in.)	Tongue Slot	
			Width (in.)	Depth (in.)
1 to 1½	2½	⅜	¼	¼
1 5/16 to 1⅞	3	½	5/16	5/16
1 11/16 to 2	3½	1	⅜	5/16
2 1/16 to 2½	3½	1¼	½	⅜

size may be altered with the expansion plug. To split the reamer, a metal slitting saw of the required thickness—usually 1/16 inch—should be used. The saw cut should not extend to the end of the reamer, but a small portion should be left solid to prevent the reamer from springing when hardening. The circular saw leaves a cut at the end of the shape shown in Fig. 65, which is extremely difficult to part after hardening. In order that the thin partition of stock may be easily severed with an emery wheel, the slot may be finished, as shown in Fig. 66, with a hand hack saw.

The expansion rod *I*, Fig. 63, should be turned to fit the taper in the reamer, the straight end being 1/32 inch smaller than the hole running through the reamer, and threaded on the end for a nut to be used in drawing the rod into the reamer. The collar shown at *F* and *H* should have a taper hole fitted to the tapered end of the reamer. The outside diameter of the collar should be a trifle smaller than the hole to be reamed. The collar, when forced on to the end of the reamer, holds the latter in place. In order to increase the size of the reamer, the collar may be driven back a trifle and the rod drawn in by means of the nut.

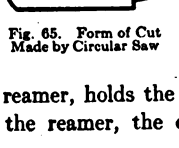


Fig. 65. Form of Cut Made by Circular Saw

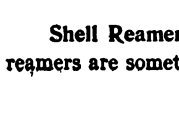


Fig. 66. Form of Cut Made by Hand Saw

After the reamer is hardened and tempered, the thin partitions left at the ends of the slots may be ground away with a beveled emery wheel, the rod inserted, the collar forced upon the end, the reamer ground to size, and the teeth backed off for clearance.

Shell Reamers. As a matter of economy, the larger sizes of reamers are sometimes made in the form of shell reamers, as shown

in Figs. 67 and 68. As several reamers may be used on the same arbor, there is a considerable saving in cost of material.

Table III gives the size and length of shell reamers from 1 inch to 3 inches in diameter, together with the size of holes, and width and depth of tongue slot.

After drilling a hole $\frac{1}{16}$ inch smaller than finish size, the blank should be placed on a mandrel, and a heavy chip taken to remove all the original surface. The drill is annealed, and then placed in a chuck on the lathe and the hole bored .005-inch smaller than finish size. After being put on a mandrel, the ends should be faced to length and the outside diameter turned, leaving .010 to .015 inch on the cutting part for grinding. The balance of the reamer should be turned to size. If it is to be a rose reamer, the edge should be chamfered the proper amount.

Cutting Slot. The reamer should be held in a chuck on the spiral head spindle in the milling machine, and the tongue slot cut.

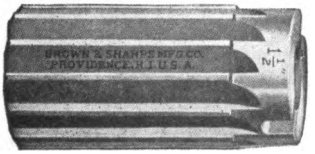


Fig. 67 Plain Shell Reamer
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

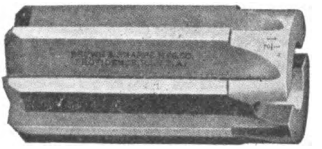


Fig. 68. Rose Shell Reamer
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

In order to get the slot central with the outside of the reamer, a cutter somewhat narrower than the desired slot should be used, which should be set as centrally as possible by measurement, a cut taken, the spiral head turned one-half way round, and another cut taken; the width of the slot should be measured, and the saddle of the machine moved by means of the graduated adjusting screw one-half the amount necessary to make the slot of the right width. The reamer may be placed on a mandrel, between centers on the milling machine, and the flutes cut.

Hardening. The reamer should be heated for hardening in some receptacle, in order that the fire may not come in direct contact with it. When it reaches a low uniform red heat, it may be placed on a wire hook, plunged into the bath and worked up and down

rapidly until all trace of red has disappeared, and should be left in the bath until cold. When cold, it may be heated to prevent cracking from internal strains. If it is to be a rose reamer, it may be left dead hard; if it is to be a fluted reamer, the temper should be drawn to a straw color. The hole should be ground to fit the shank on which it is to be used, or to fit a plug gage, if there is one for the purpose. The reamer may then be placed on a mandrel and ground according to the general directions given for grinding reamers.

The holes in shell reamers are sometimes made tapering—the end of the arbor being made of a corresponding taper—to avoid the necessity of grinding the holes, as any slight change in the size, resulting from hardening, would be compensated for by the taper hole.

Arbors for Shell Reamers. These are made as shown in Fig. 69. The shank *B* and the end *A* to receive the reamer, are made in one piece. The collar *C* having two tongues to engage in the slots in the reamer, is made of tool steel; the hole is made of a size that allows it to slide over *A*. When in position, a hole is drilled through both collar and arbor and the pin *D* driven in.

When making the collar, the hole is drilled and reamed; the collar is placed on a mandrel, the ends faced to length, and the collar

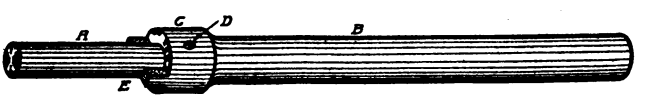


Fig. 69. Typical Arbor for Shell Reamers

turned to proper diameter. It is then removed from the mandrel, and the tongues are milled. While this is being done, the collar is held in the chuck on the spindle of the spiral head, and a side milling cutter is used. One side is milled, the spiral-head spindle turned one-half revolution, and the opposite side milled; the thickness is measured, and the saddle moved enough to bring the tongues to the required thickness, when the finish cut is taken on each side. After putting on the arbor and drilling the pinhole, the collar is removed and spring-tempered. It may now be placed on the arbor, and the pin driven in place.

When the shell reamer is made with a taper hole, the arbor is made with the end *A* of a corresponding taper. Otherwise the construction would be the same as for shell reamers having straight holes.

TAPER REAMERS

If a taper reamer is intended for finishing a hole, the same general instructions for making fluted hand reamers may be followed except that instead of being straight, the body or cutting part is tapered.

Roughing Taper Reamers. These are frequently made in the form of a stepped reamer, or it might be called a *multiple counterbore*, since each step acts as a pilot for the next larger step, Fig. 70.

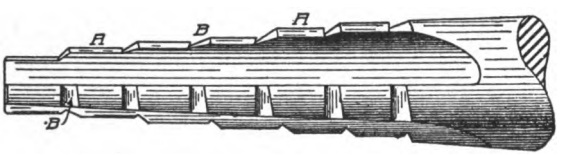


Fig. 70. Roughing Taper Reamer

The steps *A* are turned straight, each one correspondingly larger than the preceding. The cutting is done at the end of the step, *B*, which must be given clearance; this is ordinarily done with a file. The reamer may have four cutting edges, which should be cut with a milling cutter intended for milling the flutes of reamers. The number of the cutter selected will depend on the form and the amount of taper of the reamers. It is advisable to neck down into the reamer $\frac{1}{32}$ inch at the end of each step. This may be done with a round-nosed tool, or a cutting-off tool having its corners slightly rounded. The necking facilitates the filing of the cutting edges, and also allows the emery wheel to traverse the entire length of each step when grinding to size after hardening.

Roughing reamers are sometimes made of the form shown in Fig. 71. The left-hand thread, cut the entire length of the cutting

Fig. 71. Roughing Reamer with Short Steps for Breaking up the Chips
Courtesy of Union Twist Drill Company, Athol, Massachusetts

portion, breaks the chips into short lengths, and greatly increases the cutting qualities. After turning the tapered part to a size that allows for grinding, the lathe may be geared to cut a four-pitch

thread. The threading tool should be about $\frac{1}{16}$-inch thick at the cutting point, and have sufficient clearance to prevent the heel from dragging when the tool is cutting. The corners should be slightly rounded in order to reduce the tendency to crack when the reamer is hardened. The thread should be cut to a depth of from $\frac{1}{64}$ to $\frac{1}{32}$ inch. After threading, the flutes may be cut, the reamer hardened, and the temper drawn to a light straw.

When grinding a taper reamer, the proper clearance is given to the tooth for a distance of $\frac{3}{64}$ inch back from the cutting edge; the balance of the tooth is given a greater amount of clearance, as shown in Fig. 71.

FORMED REAMERS

These are used for holes of an irregular shape, or rather of a shape neither straight nor tapering. They are used chiefly by gunmakers in reaming the end of the gun barrel for the shell, and are termed, when used for this class of work, chambering reamers.

Chambering Reamers. These have a sleeve on one end as shown at *A*, Fig. 72. This sleeve is a nice running fit on a pilot, and

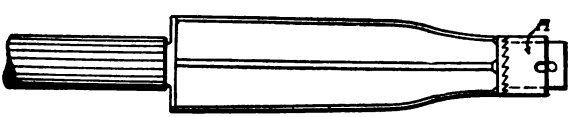


Fig. 72. Chambered Reamer for Gun Barrels with Sleeve Shown at *A*

also fits closely in the hole in a gun barrel. Teeth are cut on the end next to the cutting portion of the reamer. When the reamer is cutting, the sleeve does not revolve in the barrel, but the pilot turns in it. When the reamer is drawn out of the barrel, the semicircular slot at the end engages with the pin passing through the pilot, and the sleeve revolves and cuts away any burr that may have been thrown up when the reamer was cutting, thus preventing the burr from tearing the inside of the barrel.

It is essential that the stock be rough-turned a little above finish size and then annealed. As reamers of this form must be accurate in size and shape, it is customary to use a gage; this is generally a piece of steel in which a hole of the proper form has been reamed, and the stock cut away on one side, so that a trifle more

than one-half of the hole is left, as shown in Fig. 73. To make the reamer blank fit the gage, the operator must understand the use of hand-turning tools, as most shapes must be made with these tools.

Cutting Teeth. The teeth must be cut with a milling cutter of small diameter, following the different shapes of the reamer in order

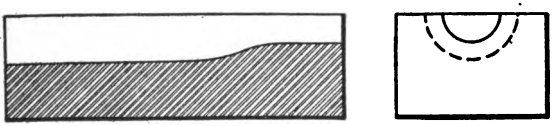


Fig. 73. Gage Used for Formed Reamer

that the top of the land may be of as uniform a width as possible. After cutting, the teeth may be backed off for clearance with a file, care being taken not to remove any stock at the cutting edge.

Hardening. When hardening, the reamer should be heated very carefully in a tube until it is of a low uniform red heat; it should then be plunged into a bath of lukewarm brine. It may be brightened and the temper drawn to a light straw. After hardening, it should be tried in the gage, and any high spots removed by oil-stoning.

Grinding. If a large number of reamers of one form are to be made, the grinding machine may be rigged with a form which makes it possible to grind many of the shapes in common use. It is found quite impracticable, however, to grind some shapes, and consequently the method just described of fitting before hardening

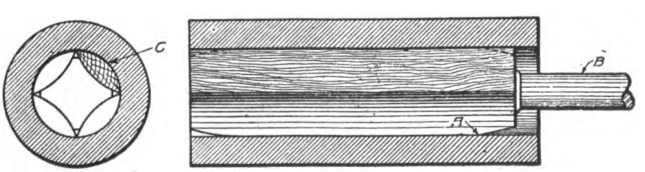


Fig. 74. Square Reamer for Finishing Long Hole

must be adopted. Excellent results are obtained with the pack-hardening process.

Square Reamers. Reamers used for finishing a long hole that must be very smooth, are often made of the form shown in Fig. 74. This reamer is drawn through the hole by means of the shank *B*, the

cutting portion being at *A*. It should cut but a very small amount at each passage through the hole. A piece of hardwood is placed on one side of the reamer, as shown at *C*. After the reamer has passed once through the hole, a piece of tissue paper is placed between the reamer and the chip, and another cut is taken, this being repeated each time the reamer passes through. Several passages of the reamer and repeated blocking between the chip and reamer, result in a beautifully finished hole of the desired size.

Hardening Form Reamers. Long reamers and similar tools, made from high-speed steel, are very likely to warp and bend unless heated for hardening in a vertical position. To accomplish this, they should be suspended by their shanks in a specially designed vertical furnace, as shown in Fig. 22. The shanks project through holes in the top of the furnace, and are held by suitable holders. As the temperature in high-speed furnaces is very great, the reamers should be pre-heated to a low red before being placed in the furnace. This pre-heating should be done in an open fire, or in a furnace where the process can be carried on slowly.

Reamers should not be heated to so high a temperature as tools that have no projecting portions. The limit of temperature for tools of this class is about 2300° F. When this temperature is reached, the reamers should be plunged vertically into a bath of cottonseed oil and worked vertically until they have cooled below a red.

As the process of hardening makes the tool extremely brittle, it is necessary to draw the temper of most forms of reamers to a full straw color (460° F.). If the reamer is slender, and is to be subjected to considerable strain, the temper may be drawn to 480° F. or 500° F. (brown color).

Reamer Holders. On account of the uncertainty of exact alignment of every part of a screw machine or turret lathe, it is desirable to use a holder that allows each part properly to align itself. The form shown in Fig. 75 is common and gives good results. It consists of the body *A*, which has a hole drilled and reamed its entire length. The hole must be somewhat larger than the shank of the reamer, $\frac{1}{16}$ inch being considered sufficient. The center *B*, of tool steel, which has the point *only* hardened should be, after hardening, .010 to .015 inch larger than the hole in the holder; the point should be ground to a 60-degree angle, and the straight part ground to a

forcing fit in the holder. After being forced to position, a hole is drilled through the holder and center, and the pin *C* driven in to keep the center from being pressed back by the reamer when in

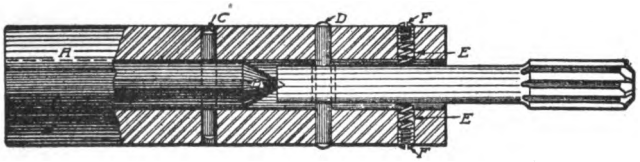


Fig. 75. Typical Reamer Holder

operation. A pin should be put through the holder at *D* and a hole $\frac{1}{16}$ inch larger than the pin should be put through the reamer shank at this point; this pin is simply to prevent the reamer from turning when it comes in contact with the work. The coil springs *EE* hold the reamer in position to enter the hole, and the proper tension is given by means of the screws *FF*.

ARBORS

Tool-Steel Mandrels. The ordinary taper arbor, known as the mandrel, is in common use in most machine shops. Up to and including a diameter of $1\frac{1}{2}$ inches, mandrels are made of tool steel, hardened all over and ground to size. Some tool-makers advocate making all mandrels up to a diameter of 4 inches in this way; others prefer hardening the ends *BB*, Fig. 76, leaving the center *A* soft, while others maintain that for mandrels above $1\frac{1}{2}$ inches in diameter, machine steel is most satisfactory if thoroughly casehardened.

When making mandrels of tool steel that are to be hardened the entire length, it is not necessary to use the best quality of steel; a

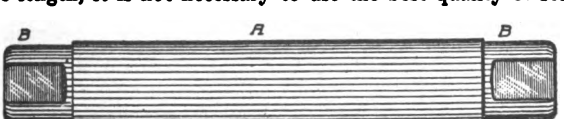


Fig. 76. Ordinary Form of Tool-Steel Mandrel

lower grade will do, if it hardens well. Select stock somewhat larger than finish diameter, say $\frac{1}{16}$ inch for sizes up to $\frac{1}{2}$ inch, $\frac{1}{8}$ inch for sizes up to 1 inch, $\frac{3}{16}$ inch for sizes up to $1\frac{1}{2}$ inches, and $\frac{1}{4}$ inch for

larger sizes. Take a chip off the outside, sufficiently heavy to remove all scale, yet leave $\frac{1}{32}$ inch for a finish cut on sizes up to $\frac{1}{2}$ inch, and correspondingly more for the larger sizes. The mandrel should now be annealed, preferably in the annealing box. The ends should be countersunk deeper in mandrels than in tools where the centers are not used after they are completed. In order that the centers may not be mutilated when driven in or out of the work, they should have an extra countersink, as at *A* in Fig. 77, or else the cut should be recessed as at *B* in Fig. 78. This operation is known as *cupping the centers*.

The ends *BB*, Fig. 76, should be turned to size (standard dimensions up to 1-inch diameter are given in Table IV), the corners slightly rounded, and the flat spots for the dog screw milled or planed. The body of the mandrel should be turned somewhat

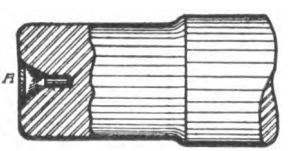


Fig. 77. Extra Countersink on Mandrel

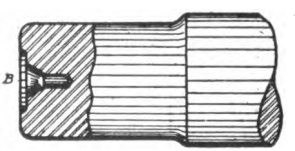


Fig. 78. Recessed Center on Mandrel

larger than finish size; those smaller than $\frac{1}{2}$ inch should have an allowance of .015 inch; from $\frac{1}{2}$ to 1 inch, an allowance of .020 to .025 inch; over 1 inch an allowance of .025 to .030 inch. As the length of a mandrel larger than 2 inches in diameter does not increase in proportion with the diameter, the amount given will generally be sufficient if proper care is used when hardening. The size should be stamped on the end next to the large end of the body.

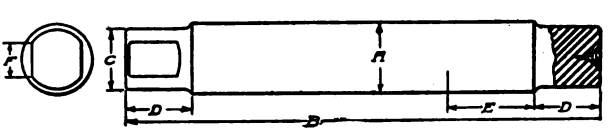
Before hardening, the centers should be re-countersunk to true them; for this operation, it is best to use a special countersink having an angle of 59 degrees instead of the regular 60-degree tool, as the former facilitates the lapping of the centers to a 60-degree angle after hardening. This is necessary on account of the unequal amount of grinding caused by the shape of the countersink.

Hardening. If a blacksmith's forge must be used when heating the mandrel for hardening, the fire should be large enough to heat the piece evenly; it is advisable to heat it in a tube. Results more

TABLE IV

Dimensions of Mandrels

(Diameters up to 1 inch)



A (in.)	B (in.)	C (in.)	D (in.)	E (in.)	F (in.)
$\frac{1}{4}$	$3\frac{1}{2}$	$\frac{7}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
$\frac{5}{16}$	4	$\frac{1}{2}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
$\frac{3}{8}$	$4\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
$\frac{7}{16}$	$4\frac{1}{2}$	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$
$\frac{1}{2}$	5	$\frac{11}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
$\frac{9}{16}$	$5\frac{1}{4}$	$\frac{3}{4}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$
$\frac{5}{8}$	$5\frac{1}{2}$	$\frac{13}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$
$\frac{11}{16}$	$5\frac{3}{4}$	$\frac{7}{8}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{11}{16}$
$\frac{3}{4}$	6	$\frac{15}{16}$	$\frac{3}{4}$	1	$\frac{3}{4}$
$\frac{13}{16}$	$6\frac{1}{2}$	1	$\frac{13}{16}$	$1\frac{1}{16}$	$\frac{13}{16}$
$\frac{7}{8}$	$6\frac{1}{2}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$
$\frac{15}{16}$	$6\frac{3}{4}$	$1\frac{1}{4}$	$\frac{15}{16}$	$1\frac{3}{16}$	$\frac{15}{16}$
1	7	$1\frac{3}{8}$	1	$1\frac{1}{4}$	1

nearly uniform can be obtained from a muffle furnace than from the open fire. In either case the piece should be turned frequently, to insure an even heat.

Best results follow if the kind of bath shown in Fig. 79 is used. Perforated pipes, which may be moved toward the center for small pieces, are used. These pipes—six in number—extend up the sides as shown. Small holes are drilled in them in such location that the water is projected toward the center of the bath. The bath is also provided with a pipe which throws a jet of water upward from the bottom, thus insuring the hardening of the center at the lower end of the mandrel. A stream must also be provided at the top as shown, to insure the hardening of the upper center hole.

The form of tongs shown at the left of bath should be used, as with these the water has free access to the upper center, which would not be the case with ordinary tongs. If a still bath is used, it should be of strong brine, and the mandrel should be worked up

and down *violently* to insure the liquid coming in contact with both centers.

A mandrel of a diameter larger than 1 inch should be removed from the bath as soon as it ceases "singing", and held in a tank of oil until cold. The ends should be brightened and drawn to a deep straw color, to toughen them so that they will not break or chip off when driven. Mandrels smaller than $\frac{3}{4}$ inch should have the temper drawn to a light straw color the entire length of the body. After hardening, the body of the mandrel should be cleaned with a coarse emery cloth to remove the scale or grease which would glaze the emery wheel.

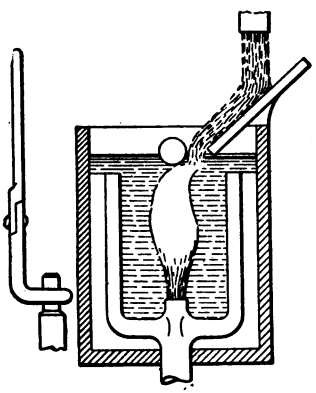


Fig. 79. Special Type of Bath for Hardening Mandrel

Finishing Centers. The mandrel should then be tested between centers to see if it has sprung more than will grind out before it reaches the proper size. The centers should now be lapped, to insure proper shape and alignment. The lap may be a piece of copper of the proper shape—60 degrees—charged with diamond dust or emery. After lapping, the centers should be thoroughly cleaned with benzine. (When using *benzine*, do not allow it to get near a flame of any kind.)

Grinding. Examine very carefully the condition of the centers of the grinder, as the trueness of the mandrel depends in a great measure on their condition. A mandrel may be ground in a lathe having a grinding attachment, or in any universal grinder. Better results can be obtained, however, with some form of grinder having a stream of water playing on the work to prevent heating, as heat is likely to spring the piece, especially if it does not run true, and thus to make the grinding heavier on one side than on the other. If a dry grinder must be used, do not force the work fast enough to heat the piece. The mandrel should be ground to within about .005 inch of size with a coarse wheel free from glaze, and then finished with a fine wheel.

Tapering. The amount of taper varies. Most manufacturers prefer a .0005-inch taper per inch of length, while others make mandrels with a .001-inch taper, maintaining that if a piece having a long hole is to be held on *any* taper mandrel, it will not fit at the part nearest the small end of the mandrel, and that consequently the turned surface will not be true with the hole; for such work, they say, a mandrel should be made for the job, having a body nearly or quite straight. They advise that the mandrel be made to taper .001 inch for every inch of length in order that it may be adapted to a greater range of work. However, a .0005-inch taper seems better for most work.

Mandrels with Hardened Ends. When making a mandrel the ends of which are to be hard, and the body soft, the general instructions given for hardening mandrels hold, except that a larger amount of stock should be left on the body. The ends should be hardened for a distance that insures the centers being hard; this can be accomplished by heating one end at a time to a red heat, and inverting under a faucet of running water. As the center is uppermost, the water can readily enter it, forcing the steam away. After drawing the temper of the ends and lapping the centers, the body may be turned and filed to size. The centers of the lathe should be carefully trued before starting this operation. If the body of the mandrel is left .008 inch to .010 inch larger after turning, and then ground to size, the results will be surer; but with extreme care a very satisfactory job may be done by the method described.

Machine Steel Mandrels. With the exception of hardening, the instructions given for making mandrels of tool steel apply to those made of machine steel. Machine steel mandrels must be casehardened. The work should be run in the fire from 7 to 10 hours after the box is red hot throughout; then it should be dipped into a bath having a jet of water coming up from the bottom, to force the steam away from the work and avoid soft spots. It is not necessary to draw the temper, as the hardening does not extend far below the surface.

Expanding Mandrels. There are several forms of expanding mandrels in common use. One form has a sleeve with a taper hole, fitting on a mandrel with a corresponding taper; the sleeve is split

to allow it to expand as it is forced on the mandrel. This form is shown in Fig. 80.

It is not advisable to give the mandrel very much taper, because a heavy cut, with the pressure toward the small end, would crowd the sleeve toward that end and release the work. Ordinarily a taper of $\frac{1}{2}$ inch to the foot will give good results.

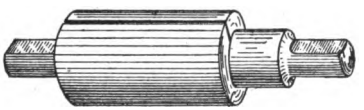


Fig. 80. Expanding Mandrel

It is obvious that the range of adjustment for such a sleeve is small, but sleeves of different diameters may be fitted to the same mandrel, the thickness of wall being varied to give the desired size. The diameter of the sleeve should be such that the work may enter without forcing, the tightening being accomplished by forcing or driving the sleeve toward the large end of the mandrel.

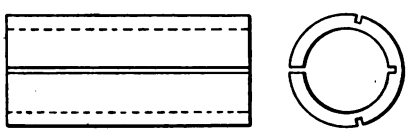


Fig. 81. Diagram Showing Method of Expanding Mandrel Sleeve

If a sleeve is needed for a special sized hole, and is to be used but a few times and through a limited range of sizes, it may be made of cast iron. A hole, corresponding in size and taper to its mandrel, is bored so as to allow the small end of the mandrel to go through and be flush with the end of the sleeve. The sleeve should be forced on the mandrel and turned to size; the outside diameter should fit the hole in the piece to be machined when the sleeve is at the small end. In order that the sleeve may be expanded, it is split as shown in Fig. 81. This should be done in the milling machine, the sleeve being held by the ends in the vise, and the cut made with a metal slitting saw.

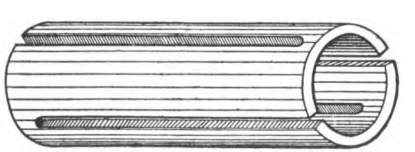


Fig. 82. Method of Splitting Sleeve for Uniform Expansion

When the sleeves are intended for permanent equipment, it is good practice to make them of either machine steel or tool steel; if of the former, they may be casehardened; if of the latter, they may

be hardened and spring-tempered. In either case the hole should be .010 inch small, and the outside diameter .020 to .025 inch large, and ground to size after hardening. A method of splitting the sleeve for an expansion more nearly uniform is shown in Fig. 82; small sizes have four cuts for adjustment, while the larger sizes have six or eight.

On account of its peculiar construction, the sleeve shown in Fig. 82 must be so held while grinding the hole that it will not spring. To do this, the sleeve may be placed in a hole in a collar and held rigidly in position by several drops of solder. In order that the solder may stick, the outside of the sleeve must be brightened, and the metal heated until solder will melt on its surface. Care must be exercised, as the surface of iron commences to oxidize at 430° F., and soft solder melts at about 400° F.; and as solder will not stick to an oxidized surface, the metal must not be heated above 400 degrees. For this class of work always use soft solder, made by melting together equal parts of tin and lead.

Many mechanics think it is impossible to solder cast iron, but such is not the case. If soft solder is used and care is exercised in heating, little or no trouble will be experienced.

When soldered securely, the collar should be placed in the chuck on the grinding machine, and the hole ground to the desired size, after which it is heated to melt the solder, and the sleeve removed from the collar. It can then be placed on the mandrel, and the outside diameter ground to the proper size.

Eccentric Arbors. Arbors are made eccentric in order that the outside of a piece of work may be made eccentric to the hole running through it, as shown in Fig. 83.

When making an eccentric arbor, the general directions given for making mandrels should be followed, except that the centers must be rather small. The mandrel should be placed in a V-block or in a pair of centers; and by means of a surface gage, the needle of which has been set at the exact height of the center, a line may be drawn, as shown in Fig. 84, across each end of the mandrel.

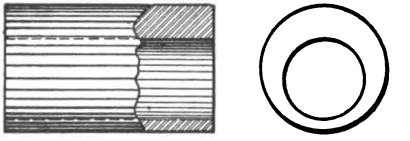


Fig. 83. Part Section and End View of Piece of Work with Eccentric Hole

The mandrel may now be turned so that the line will be vertical; the point of the surface-gage may be raised to give the required amount of eccentricity, and a line, as shown in Fig. 85, scribed on each end. The ends should be prickpunched where the lines intersect, and drilled and countersunk at this point.

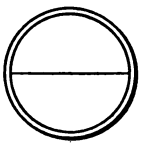


Fig. 84. First Line for Locating Eccentric Center

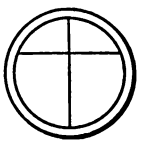


Fig. 85. Second Line for Locating Eccentric Center

After hardening, both pairs of centers should be lapped to shape. The centers, marked *AA*, Fig. 86, must be used when grinding the mandrel to size, or in turning work which is to be concentric with the hole, while the centers *BB* are used when turning the eccentric parts.

Use of Jig for Accurate Work. This method of laying off and drilling the eccentric center, may not give the necessary accuracy,

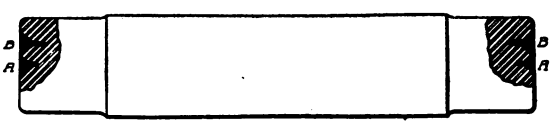


Fig. 86. Part Section of Mandrel with Eccentric Centers Located

and if it does not a jig must be used in drilling the center holes. A suitable jig is shown in Fig. 87. The ends of the arbor must be turned to fit the hole *A* in the jig, which is a collar having a straight hole through it. A piece of steel, which is a forcing fit in this hole, has a hole the size of the centering drill, laid off with the proper amount of eccentricity. This piece of steel is forced to the center of the collar, at *B*. A straight line should be drawn across the collar and down the beveled edges, as shown at *C*. A line should now be scribed the entire length of the mandrel, which should be set to match the line on the jig. The jig is secured in its proper position by means of the set screws.

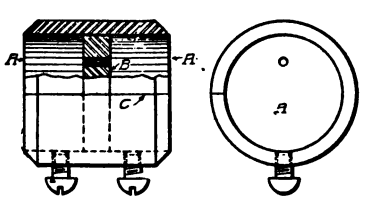


Fig. 87. Jig for Locating Centers

Use of Mandrels with Two Centers. For machining a cylindrical piece which has a hole through it to receive an arbor, and the faces of which are not parallel, Fig. 88, it is well to use a mandrel having two sets of centers, Fig. 89, *AA* being the regular centers, while the eccentric centers, *BB*, should be equidistant from the regular centers, but on opposite sides.

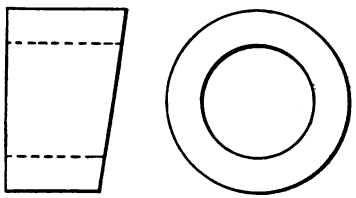


Fig. 88. Cylinder with Faces not Parallel

Milling-Machine Arbors. Arbors for milling machines should be made from steel strong enough to resist without twisting or springing, the strain caused by tightening the nut. When a limited number of arbors are made, tool steel is generally used; but for many milling machines, necessitating a great many arbors, a lower priced steel having the necessary stiffness is selected.

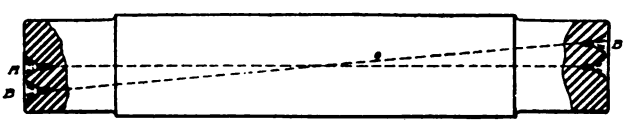


Fig. 89. Mandrel Showing Two Sets of Centers

After centering and squaring the ends, a chip is turned the entire length of the piece, to remove all the outer surface. The ends *D* and *C*, Fig. 90, are next turned to size, and the tenon milled to the desired dimensions. In milling for the tenon, the arbor

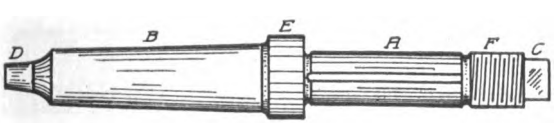


Fig. 90. Milling-Machine Arbor

should be held between centers, and the cutting done with an end mill of the form shown in Fig. 91, the circumference of the cutter leaving the proper shape at the end of the tenon. The centers should be hardened, and the temper drawn to a straw color. If

the projection on the end of the arbor at *C*, Fig. 90, is to be run in a socket in the tail block of a milling machine, it must be hardened the entire length, in which case the thread for the nut should be cut before the end is hardened.

If a lathe having a taper attachment is used, there is no particular method of procedure other than roughing the arbor nearly to size before either the taper or the straight end is finished. It will save time, however, if the straight end *A*, Fig. 90, is roughed first, then the taper *B* roughed and finished, after which the shoulder *E*, and the straight part *A*, may be turned to size and finished. If the projection *C* is to run in a socket, it should be turned .010 or .015 inch

Fig. 91 Left-Hand End Mill
Courtesy of Union Twist Drill Company, Athol, Massachusetts

above finish size, and ground to the proper dimensions. If it is necessary to use a lathe having no taper attachment, the necessary taper must be obtained by setting over the tailstock. In this case it is better to turn and fit the taper first, for otherwise the centers would become changed enough to throw the arbor out of true.

These instructions should be followed wherever a straight and taper surface are to be turned on the same piece of work, in a lathe having no means of turning tapers other than by setting over the tailstock. Where extreme accuracy is required, it is advisable to leave the straight and taper parts a few thousandths of an inch above size, and to grind to size all over after the spline cut is taken.

Milling-machine arbors should have a spline slot cut the entire length of the part that is to receive the cutters and this can best be done in a shaper. Before putting the arbor in the shaper vise, a hole should be drilled close to the shoulder into which the tool is to run. The drill used should be about $\frac{1}{32}$ inch larger in diameter than the thickness of the splining tool, and the hole drilled a trifle deeper than the slot to be cut. When the arbor is placed in the vise, a piece of sheet brass or copper should be placed between the arbor and the vise jaws to prevent bruising the arbor.

Nuts. The nut is usually made of machine steel, casehardened. A bar of steel $\frac{1}{16}$ inch larger than the finish size of the nut is selected, and a piece $\frac{1}{16}$ inch longer than finish length is cut; it is then put in a chuck on the lathe, the hole drilled, and the thread cut. If no tap of the desired size is at hand, the thread may be chased; if a tap can be obtained, the thread should be chased nearly to size and finished with the tap. Before being taken from the chuck, the end of the nut should be faced, and the hole recessed to the depth of the thread for a distance of two threads; after being removed from the chuck, it should be placed on a threaded mandrel the threaded portion of which fits the thread in the nut. The nut should be turned to size and length, and the two opposite sides milled to receive the wrench used in tightening. Fig. 92 gives two views of the nut. It should be made and casehardened before the thread is cut on the arbor, in order that the thread may be made to fit the nut. Milling-machine arbor nuts should fit the thread on the arbor in such a manner that they may be turned the entire length of the thread without the aid of a wrench, yet not be loose.

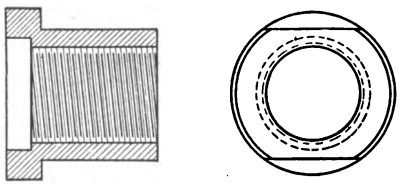


Fig. 92. Details of Nut for Milling-Machine Arbor

TAPS

Process of Making. *Use of Screw Dies.* When making taps $\frac{1}{4}$ inch in diameter and smaller, the threads are often cut with screw dies, of which there are two styles. The form of screw plate shown in Fig. 93 is termed a *jam die plate.* With this form the die is opened to allow the wire to pass through, until it is even with the outside edge of the die, which is now forced into the wire by means of the adjusting screw; the screw plate is revolved until a thread of the desired length is cut. This operation is continued, the die being closed a trifle each time, until the right size is obtained. The method taken for gaging the correct size varies in different shops; if only one tap is made, the tops of the threads are measured with a micrometer caliper; but for many taps of the same size, such as for sewing machines, guns, and bicycles, a *sizing die* is used to give the

threads an exact size. The threads are cut to within a few thousandths of an inch with the die plate, and finished with the sizing die. One form of sizing die is shown in Fig. 94.

Where a great many taps of one size are cut, it is customary to use several dies of different sizes, one of which, the finishing die, is

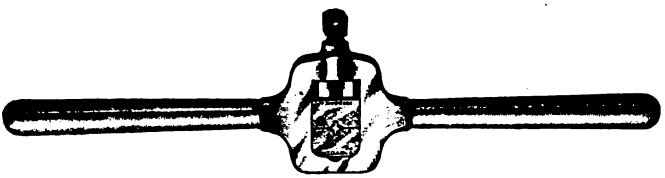


Fig. 93. Typical Jam Die Plate
Courtesy of Morse Twist Drill and Machine Company, New Bedford, Massachusetts

always made adjustable. The roughing dies may be made solid or adjustable, but the finishing must be adjustable for wear and for the changing size of the taps. These dies are sometimes held in separate holders of the form shown in Fig. 94, but a more convenient form of holder is the one shown in Fig. 95. If all the dies are in one holder, they are not scattered around the shop. When many taps are made at a time, the work can be done better and more cheaply if the wire is held in a chuck in a lathe. The die plate should be placed

Fig. 94. Simple Form of Sizing Die

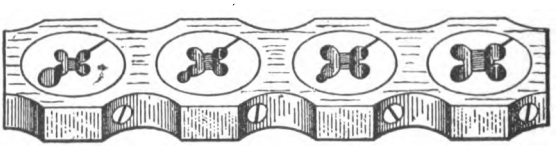


Fig. 95. Form of Gang Die Holder

against a drill pad held in the tail spindle of the lathe, in order to insure starting the threads true. The largest die should of course be run on first, the second largest next, and so on to the finish die.

Stock. For taps up to and including those $\frac{1}{4}$ inch in diameter, it is customary to use a drill rod. The taps should be chamfered for a

Fig. 96. Drill Rod for Small Taps

distance of three or four threads, as shown at *A*, Fig. 96, in order that the point may enter the drilled hole.

Taps larger than $\frac{1}{4}$ inch are made from tool steel. Taps of $\frac{1}{4}$- to $\frac{1}{2}$-inch diameter should be made of stock at least $\frac{1}{16}$ inch large, which should be centered quite accurately with a small drill, because a large center hole weakens the tap and increases the liability of its cracking when hardened. After taking a chip sufficiently deep to

Fig. 97. Types of Hand Taps. Left-Taper Tap; Center-Plug Tap; Right-Bottoming Tap
Courtesy of Wiley and Russell Manufacturing Company, Greenfield, Massachusetts

remove all the outer coating, the tap should be box annealed, if possible.

Tap Sets. Taps for general use around the shop are often made in sets of three. The first tap to enter the hole is called the *taper tap*, because of the long chamfering or taper. The second is known as

the *plug tap;* this tap has the first two or three end threads chamfered, and is used when the screw is to go nearly to the bottom of the tapped hole. The *bottoming tap* is used when the thread is to go to the bottom of the hole; the end of this tap is not chamfered, Fig. 97.

Hand Taps. Hand taps are intended for tapping holes by hand, and are usually made in sets of three, as previously explained.

Fig. 98. Threading Tool for Hand Taps
Courtesy of Armstrong Brothers Tool Company, Chicago

After being annealed, the shank should be turned to size and the square end milled for a wrench. The body should now be turned to size, and the thread cut. Before turning any of the parts to size or starting to cut the thread, be sure that the centers of the lathe are in good condition—the live center should run true, the dead center should fit the center gage and be in good shape.

It is advisable to cut the tap slightly tapering, the thread being from .0005 to .001 inch smaller at the end toward the shank. This prevents the tap from binding when slightly worn, yet does not taper enough to affect the accuracy of the thread. The thread tool should be an exact fit to the gage, and placed in the tool post so that the top of the shank stands about level. The top of the blade shown at *A*, Fig. 98, should be ground parallel with the top of the shank and the cutting point should be set at the exact height of the point of the head center. Many tool-makers consider it advisable to rough the thread nearly to size with a single-point tool, finishing it with a chaser held in the same holder. A chaser blade is shown in Fig. 99.

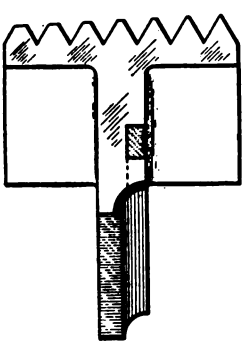


Fig. 99. Chaser Blade

Milling Flutes. After the thread is cut to size and the end chamfered, the tap is ready to be grooved in the milling machine. The tap is held between centers, and the grooves cut with a cutter especially adapted to the size and style of tap. While the grooves

are best cut with a milling-machine cutter, it is possible to cut them in a planer or a shaper, using a tool of the proper shape. Great care must be used not to stretch the tap by heavy chips, or by using a dull tool.

The grooves cut in taps are ordinarily termed flutes. When making taps for the market, it is usual to cut four flutes in all taps up to and including those 2½ inches in diameter. But when taps are made in the shop where they are to be used, the number and shape of the grooves depend on the nature of the intended work. A tap that is to run through the work without any backing out can have a flute of a shape different from one that is to tap a deep hole in a piece of steel where it is necessary to reverse the motion of the tap every two or three revolutions to break the chip, and also to allow the lubricant to reach the cutting lips.

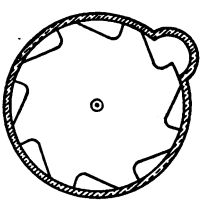


Fig. 100. Threading Hole Where Part of Wall Is Cut Away

While all taps up to and including those 2½ inches in diameter are usually given four straight flutes, spiral flutes are sometimes desirable, especially with small taps, for some classes of work. With spiral flutes, it is generally necessary to cut a smaller number than with straight flutes, and, as taps are not ground after hardening, there is no objection to giving an odd number of teeth, as in the case of a reamer. Three spiral flutes are often cut.

If a tap one inch in diameter, having four flutes of the regulation width, were used to tap tubing having thin walls, the tubing between the lands would have a tendency to close into the flutes of the tap and might break the tubing or the tap. In such a case there should be double the number of flutes, in order to provide enough lands to hold the tubing in shape. If the hole to be tapped has part of its circumference cut away, as shown in Fig. 100, more than four lands are necessary. For general machine-shop work, however, four flutes work well in hand taps up to and including those 2½ inches in diameter. For larger sizes, some tool-makers advocate six flutes; others claim best results from taps having four flutes, regardless of size. The class of work and the stock used in the individual shop must determine this.

Forms of Flutes. The most commonly used form of flute is that cut with a convex milling cutter for milling half-circles, Fig. 101. The advantages claimed for this form are (1) that the flutes are deep enough to provide for the chips, and yet leave the lands as strong as need be; and (2) that the form of the back of the land is such that the chips cannot be wedged between the land and the work when the motion of the tap is reversed. The form of groove made with this cutter is shown in Fig. 102. In order to support the tap when starting to cut, and prevent cutting the hole large at the outer end, hand taps have their lands left wider, *A*, Fig. 102, than the lands on machine taps. If the forms of cutter illustrated in Fig. 101 or Fig. 103 are used, the width of lands as shown at *A* may be one-fourth the diameter of the tap. Fig. 104 shows a special form of cutter. It does not make so deep a groove, Fig. 105, in proportion to the width, as a tap and reamer cutter.

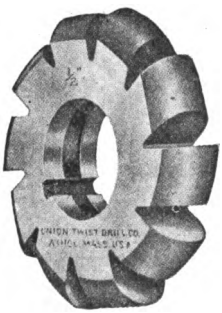


Fig. 101. Convex Cutter
Courtesy of Union Twist Drill Company, Athol, Massachusetts

After cutting the grooves, the lands should be backed off to give the tap cutting edges; this is usually done with a file. Commence at the heel of the land *A*, Fig. 106; file the top of the land and gradually approach the cutting edge, making sure that no stock is removed at that portion—simply bring

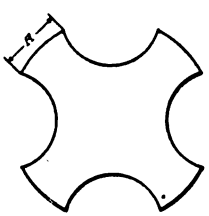


Fig. 102. Section of Milling Cutter

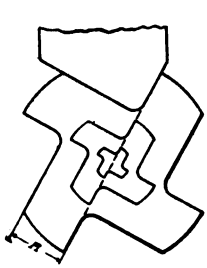


Fig. 103. Special Brown and Sharpe Form of Milling Cutter

it to a sharp edge. Enough should be filed off the heel *A* to make it cut readily, yet not enough to cause it to chatter. The size and number of threads per inch should be stamped on the shank of the tap. If it has a thread differing from the one in general use in the shop, that should also be stamped on the shank, as "U. S. S." if it is a United States Standard thread.

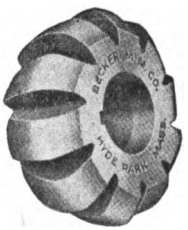


Fig. 104. Special Milling Cutter for Grooving Taps
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

Below are given the numbers of the cutters for different diameters of taps when the form shown in Fig. 104 is used:

No. 1 cutter cuts taps up. . . . . to $\frac{1}{4}$-inch diameter
No. 2 cutter cuts taps from $\frac{5}{32}$-inch to $\frac{1}{2}$-inch diameter
No. 3 cutter cuts taps from $\frac{9}{32}$-inch to $\frac{3}{4}$-inch diameter
No. 4 cutter cuts taps from $\frac{7}{16}$-inch to $\frac{1}{2}$-inch diameter
No. 5 cutter cuts taps from $\frac{11}{16}$-inch to $\frac{1}{4}$-inch diameter
No. 6 cutter cuts taps from $\frac{13}{16}$-inch to $1\frac{1}{2}$-inch diameter
No. 7 cutter cuts taps from $1\frac{5}{16}$-inch to $1\frac{3}{4}$-inch diameter
No. 8 cutter cuts taps from $1\frac{11}{16}$-inch to 2 -inch diameter

Fig. 105. Groove Made by Becker Special Cutter

Hardening. If but a few taps are to be hardened at a time, it is customary to heat them in a gas jet or an open fire of charcoal or hard coal. It is advisable, however, to heat them gradually in a tube. They should be plunged one at a time into the bath a little above the threads, and worked up and down and around in the bath to prevent soft spots. Excellent results follow the use of the bath shown in Fig. 79. Taps of 1-inch diameter and smaller should be

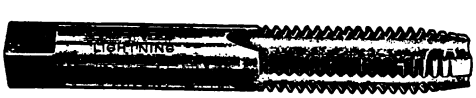


Fig. 106. Tap Showing Method of Filing Away Teeth at the Point
Courtesy of Wiley and Russell Manufacturing Company, Greenfield, Massachusetts

left in the bath until cold; larger ones may be removed from the bath as soon as the singing noise ceases, immediately plunged into oil, and left until cold. For taps of less than $\frac{1}{4}$-inch diameter, the citric acid bath will be found satisfactory; for larger taps, strong brine is advisable.

Fig. 107. Tap with Long Shank for Automatic Machines
Courtesy of Wiley and Russell Manufacturing Company, Greenfield, Massachusetts

To have the tap retain as nearly as possible its size and correctness of pitch, use the pack-hardening process. Run taps $\frac{1}{8}$ inch in diameter and smaller for $\frac{1}{2}$ hour after they are red hot; taps $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter, 1 hour; taps $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, $1\frac{1}{4}$ hours; taps of a diameter larger than 1 inch, 2 hours. Harden in a bath of raw linseed oil.

Grinding. It is advisable to grind the flutes of the taps with an emery wheel of the proper shape in order to brighten the surface so that the color will be readily seen when drawing the temper. Grinding also sharpens the cutting edges, and breaks the burrs that have been thrown between the teeth when cutting the flutes. The temper should be drawn to a full straw color. Much more satisfactory results may be obtained by heating the taps in a kettle of oil, drawing the temper to a point from 460° F. to 500° F., according to the size of the tap and the nature of the stock to be cut.

Machine Taps. As the name implies, machine taps are intended for screw machines, tapping machines, and lathes. They are held in chucks or collets by their shanks, and are supported firmly. Consequently the lands may be narrower than those of hand taps to make them offer less surface to the work, thereby reducing the amount of frictional resistance. Also, they may be relieved between the teeth, by filing with a sharp-cornered three-square file, commencing at the heel of the tooth and filing nearly to the cutting edge. It is not good practice to relieve the teeth very much, because chips may be drawn between the work and the lands when backing out of the work. When taps are to be used in an automatic tapping machine without reverse motion, the shanks are left long as shown in Fig. 107, in order that the nuts may pass over the thread and on to the shank. When this is full, the tap is taken from the machine and the nuts removed. This can be readily done, as they will pass over the end of the shank.

If a tap is to be used on nuts whose holes are punched to size,

much better results are obtained by using a tap with five flutes, Fig. 108, instead of four. The uneven number of cutting edges

Fig. 108. Tap with Five Flutes

reduces the likelihood of an imperfectly tapped hole, while the extra land furnishes additional support.

Taper Taps. When cutting the threads of a taper tap, Fig. 109, it is necessary to use a lathe having a taper attachment, as the pitch of the threads is not correct if the taper is obtained by setting over the tailstock. Like machine taps, the teeth of a taper tap must be relieved back of the cutting edge. In setting

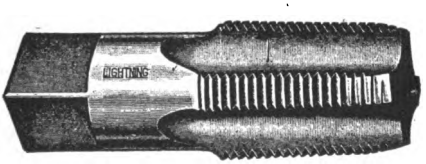


Fig. 109. Typical Taper Tap
Courtesy of Wiley and Russell Manufacturing Company, Greenfield, Massachusetts

the threading tool for cutting taper taps, care should be taken that it is square with the axis of the tap, rather than square with the taper sides.

Screw Die Hobs. Die hobs are finish taps for sizing the thread in screw cutting dies. The several flutes are narrower than those of an ordinary tap, and the lands are correspondingly wider. The tap shown in Fig. 110 has eight flutes. The increased number and broader lands support the tap while running through dies whose clearance holes are drilled, in order to remove burrs thrown in the threads when drilling. It is customary to give screw die hobs from six to ten flutes.

When hobs are used for solid dies, they must be of exact size. When intended for tapping adjustable dies, such as are ordinarily used for cutting threads in screw machine work, the hobs are made

from .003 to .005 inch above the size of the screw to be cut. The extra size gives relief to the threads of the die.

While it is generally considered advisable to run one or more taps through a die before the hob, some tool-makers consider it better to

Fig. 110. Screw Die Hob
Courtesy of Wiley and Russell Manufacturing Company, Greenfield, Massachusetts

make a hob that will do all the cutting, claiming that no two taps can be made and hardened so that the pitch will be exactly the same. In such cases a hob is made that will cut a full thread by passing through the die, Fig. 111.

Some manufacturers cut the thread tapering for about three-quarters of its entire length, leaving the balance straight for use in sizing the die. Others cut the thread straight and taper the outside for three-quarters of its length. If the threads are cut tapering, they must be relieved back of the cutting edges.

When hardening large hobs, those, say, 3 inches in diameter and larger, it is a good plan to fill the threads with the mixture of charred leather, flour, and salt, used for hardening twist drills. After this dries, the taps may be heated and hardened. Best results follow if they are hardened in a bath of lukewarm brine.

Fig. 111. Hob for Cutting Full Threads
Courtesy of S. W. Card Manufacturing Company, Mansfield, Massachusetts

Adjustable Taps. A solid tap made to cut to exact size, having no leeway for wear, soon becomes too small. This fault is overcome by making a tap that may be adjusted from time to time. Another advantage of adjustable taps is that the holes

may be tapped to fit hardened screws, which vary in size because of the hardening.

Probably the most common form of adjustable tap is the one shown in Fig. 112. This tap is made in one piece, and then split. It

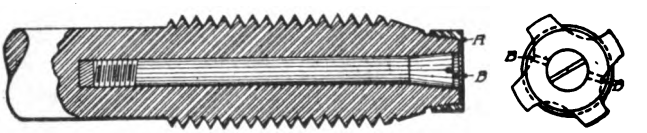


Fig. 112. Section of Common Form of Adjustable Tap

has some means of adjustment whereby the tap can be expanded or contracted through a limited range. This can be accomplished by using a taper-bodied screw. The hole to receive the screw should be drilled, tapped, and taper-reamed before the tap is turned to size. The thread should then be cut, and the taper thread cut on the end at *A*. There is less tendency to spring, when the tap is hardened, if the projection shown in Fig. 113 is provided; this may be ground off after the tap is hardened and tempered. When the flutes have been cut, the tap should be split in the milling machine by using a metal slitting saw, the tap being held between centers. It is split on two opposite sides, as shown at *B*, Fig. 112. The splitting should not go to the end of the projection.

For hardening taps, pack hardening is best. If, however, this method cannot be used, the tap should be heated very carefully in a muffle furnace, or in a tube, the hole for the adjusting screw having previously been plugged with fire clay mixed with water to the consistency of dough. When heated to the proper degree, the tap should be dipped into a bath of lukewarm brine, and worked up and down rapidly. After hardening, it should be ground in the flutes, and the temper drawn to a full straw color. The projection on the end may be ground off, the taper screw inserted, and the locking nut *B*, Fig. 112, screwed to place. This nut has a taper thread cut inside to correspond with the thread on the tap at *A*. It will be found necessary

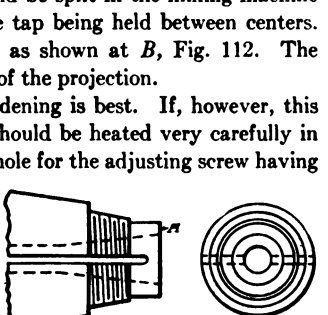


Fig. 113. Split Tap

to cut the taper thread on the tap and in the nut, by means of the taper attachment.

Inserted-Blade Taps. The first cost of an inserted-blade tap may not be much less than that of a solid tap of the same size, yet the comparative cheapness of new blades, which can be inserted in the same body or holder when the first set becomes worn, makes this form very valuable for taps larger than 1½ inches in diameter. The tap shown in Fig. 114 may also be used as an adjustable tap. The shank or holder *A* is made of machine steel, and the adjusting

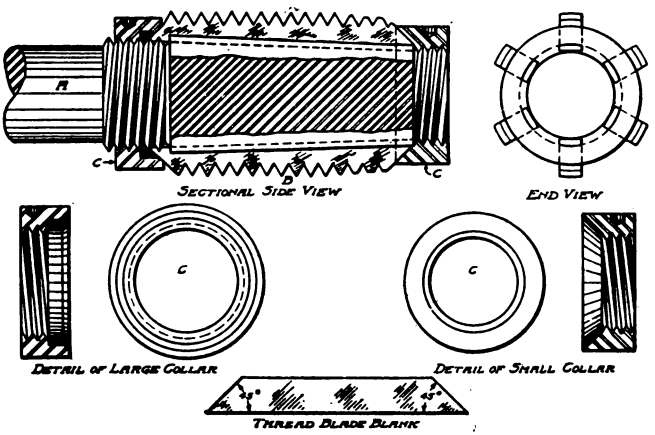


Fig. 114. Details of Inserted Blade Tap

collars *C*, are beveled on the inside at one end, at an angle corresponding to the angle on the ends of the blades. An angle of 45 degrees will be found satisfactory.

After turning the body or holder to size, and cutting the threads to receive the nuts, the slots for the blades may be milled. These should be cut deeper at the cutting end, in order that any change in the location of the blades may alter the size of the tap. A taper of $\frac{1}{16}$ inch in 3 inches is ample. If the slots are milled on the universal milling machine, and the tap held in the universal centers, Fig. 115, the spiral head may be depressed sufficiently to give the desired angle. Sometimes a pair of centers mounted on special ways is used and is

held in the milling-machine vise at the desired angle. The milling cutter should be set about $\frac{1}{32}$ inch ahead of the center, in order that the face of the blade may be milled enough to take any inequality in the teeth at the cutting face. This is occasioned by the thread

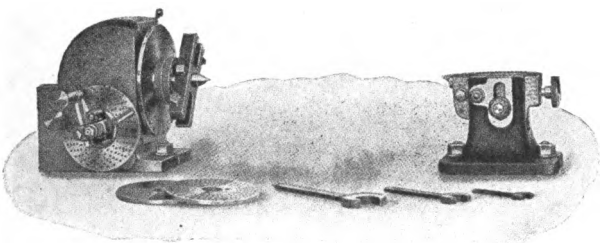


Fig. 115. Pair of Centers for Milling Taps
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

tool striking the face when it starts to cut. The amount milled should be just enough to leave the cutting face radial. The blades should be of an exact length and fit accurately in the slots. A gage of the form shown in Fig. 116 will insure uniform length. After the blades have been carefully fitted to the slots and to the gage, they should be inserted in the holder and secured by the nuts, as shown in Fig. 114. The outside diameter is then turned about .005 inch smaller than the size the tap is to cut, and the threads very carefully

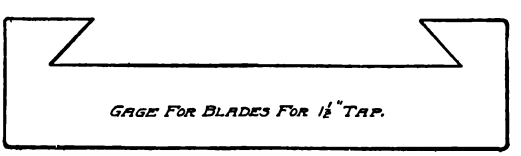


Fig. 116. Tap Gage

cut; after this the faces of the blades should be milled, as explained, the cutting end chamfered, and the necessary amount of clearance given the cutting edges by filing. The blades are now ready for hardening.

During this process the blades should be subjected to a slow heat in a muffle furnace or a tube. When the blades reach a low,

uniform red heat, they should be immersed in a bath of lukewarm water or brine, and worked up and down to insure uniform results. After hardening, they may be brightened and drawn to a deep straw color.

For this operation it is well to place all the blades in a pan having a long handle, as shown in Fig. 117. Coarse sand to a depth of about 1½ inches may be placed in the bottom of the pan with the blades. The pan should be placed over a bright fire, and shaken carefully, so that the teeth will not be dulled by striking the other hardened blades. The motion causes the pan to heat uniformly, and the sand keeps the surface of the work bright so that the temper colors may be readily seen. This method of drawing temper will be

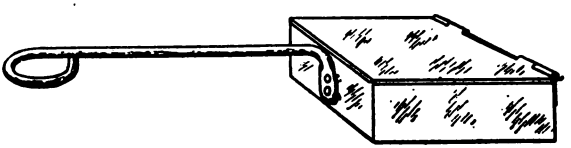


Fig. 117. Tempering Pan for Taps

found very satisfactory on many classes of work. It is also used extensively where a great many pieces are to be colored uniformly by heat.

Threads. *Forms.* Taps one-quarter of an inch in diameter and smaller are, as a rule, made with V-threads whose sides form an included angle of 60 degrees, or, with round top and bottom threads. Taps larger than one-quarter inch are made with the United States Standard form of thread, which has an included angle of thread of 60 degrees, the same as the V-form, but with one-eighth of the altitude removed from the top and one-eighth filled in at the bottom, as shown in Fig. 118. The V-shaped thread taps are made in various pitches for each different size, but the United States Standard has a definite pitch for each diameter.

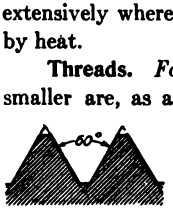


Fig. 118. Form of U. S. Standard Thread

Diameters. Below are given formulas for finding the diameters at the bottoms of threads, or tap-size drills for the V-thread, and the United States Standard thread. In both formulas, S = desired size; T = diameter of tap; N = number of threads per inch.

Formula for V-thread:

$$S = T - \frac{1.733}{N}$$

Formula for the United States Standard thread:

$$S = T - \frac{1.3}{N}$$

As an example of the working of the formulas, we will solve a problem by each.

(a) The tap size drill for a $1\frac{1}{4}$-inch diameter by 6-thread V-tap may be derived by applying the formula for the V-thread, as follows:

$$S = 1\tfrac{1}{4} - \frac{1.733}{6}$$
$$= 1.25 - .2888 = .961 \text{ in.}$$

(b) The tap size drill for a 1-inch diameter by 8-thread U.S.S. tap may be derived by applying the formula for the United States Standard thread, as follows:

$$S = 1 - \frac{1.3}{8}$$
$$= 1 - .1625 = .8375 \text{ in.}$$

Taps for Square Threads. Although the square thread is not so extensively used as formerly, having given place in many shops to the *Acme Standard*, yet it is sometimes necessary to make taps for this form.

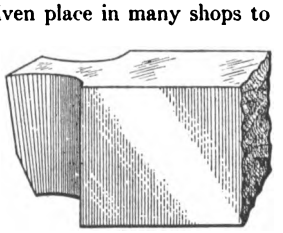


Fig. 119. Gage Thread Tool

Steel sufficiently large should be selected, the decarbonized portion removed, and the shank turned to size. The square should be milled for a wrench and the size and number of threads per inch stamped on the shank. The cutting end of the tap is turned to size, the necessary amount of taper given the tap, and then the threads are cut.

The tool used for cutting square threads is similar in form to a cutting-off (parting) tool, except for its angle side rake. It should be made of the proper thickness at the point, but should be some-

what narrower back of the cutting end, Fig. 119, in order that it may clear when cutting.

The thickness of the cutting end should be one-half the distance from the edge of one thread to the corresponding edge of the next thread. For a square thread of ½-inch pitch, the land and space together would be ½ inch, while the land and space would each be ¼ inch wide. The point of the tool should be ¼ inch thick.

The sides of the tool from *A* to *B*, Fig. 120, must be inclined to the body as shown, the amount of the inclination depending upon the pitch of the thread and the diameter of the tap to be cut. This may be determined by the method shown in Fig. 121. Draw the line *AB* and at right angles to it draw *CD*, whose length must be equal to the circumference of the thread to be cut, measured at the bottom or root of the thread. On *AB* lay off from the point *C* a distance *EC* equal to the pitch of the thread to be cut, and draw the line *DE*. The angle *CDE* will represent the angle of the side of the thread; the angle of the side of the cutting tool must be sufficiently greater to give the necessary clearance. It is advisable to cut the thread first with a tool somewhat narrower than the required width, and to finish with a tool of the proper thickness.

Fig. 120. End View of Gage Thread Tool

Square-thread taps may be fluted according to directions given for V-thread taps. If a tap is intended to cut a full thread, it must be well backed off, in order to avoid the necessity of using so much force that the tap would be broken. When a tap is to be used to size a hole whose thread has been cut by a smaller tap, very little clearance is necessary.

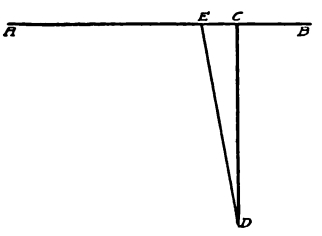


Fig. 121. Diagram Showing Angle of Thread Tool

Left-Hand Thread. Taps are made with left-hand thread for tools requiring such thread. Many times fixture jaws are made in pairs, that is, two jaws are made to hold the work, and are opened and closed by turning a screw which passes through a threaded por-

tion in each. One jaw has a right-hand thread tapped in it while the other has a left-hand thread. The screw is made with a righthand thread on one portion and a left-hand thread on the other. If the pitch is the same on both threads the jaws will open and close uniformly and will accurately center pieces of various sizes.

It is necessary, of course, to back off the cutting lips of a left-hand threaded tap on the opposite side of the end from that backed off on one that is right-hand threaded.

Left-hand threaded taps are stamped with an L to prevent confusion, for while it is possible to detect the difference in the way the threading runs, in the case of coarse pitches, yet without a distinguishing mark the workman would often waste valuable time trying to use a left-hand tap for a right-hand tap.

Steel for Taps. While ordinary crucible tool steel is extensively used in making taps, many makers assert that the best steel for use

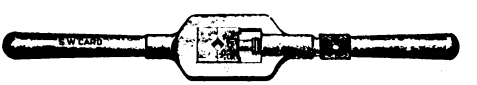


Fig. 122. Typical Tap Wrench
Courtesy of S. W. Card Manufacturing Company, Mansfield, Massachusetts

in tapping cast iron and brass is one which has, in addition to the usual composition of high-carbon crucible tool steel, from two to three per cent tungsten. It is said that the amount of change in length due to hardening is the same for tungsten steel as for most tool steel.

Vanadium tool steel is used rather extensively in making taps for tapping steel and is especially satisfactory in making long stay-bolt taps. It is strong and is not so easily broken by shock and irregular strains as ordinary tool steel, nor is it so easily affected by slight variations of heat when hardening.

There are several oil-hardening steels on the market that have won the approval of the tap-makers. The taps made from some of these steels, it is asserted, will not change in pitch when hardened.

Tap Wrenches. A solid tap wrench may be made for taps whose squares are all of a size. This wrench is forged nearly to

shape, the handles turned to size in the lathe, and the square hole in the center drilled and filed. For general shop work adjustable tap wrenches are commonly used, Fig. 122.

Tap Holders. When holes are to be tapped to a uniform depth in a screw machine or a turret lathe, a tap holder is used which automatically releases the tap when it reaches the required depth. A very common form, which gives excellent results when properly made and adjusted, is shown in Fig. 123. Its essential parts are a sleeve *A*, which fits the tool holes in the turret of the screw machine, and a tap holder *B*, which fits the hole in the sleeve in such a manner as to slide longitudinally. The sleeve should be made of tool steel, if of a diameter that makes the wall around the hole thin; the hole should be drilled and reamed to size, and the outside turned to size. The portion of the sleeve which enters the hole in the turret must be a snug fit. The tap holder should be made of tool steel, or of a

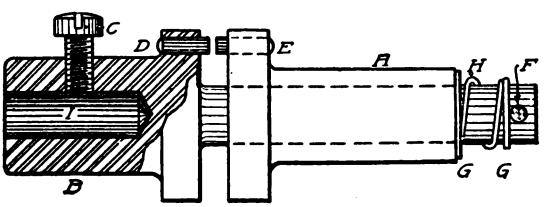
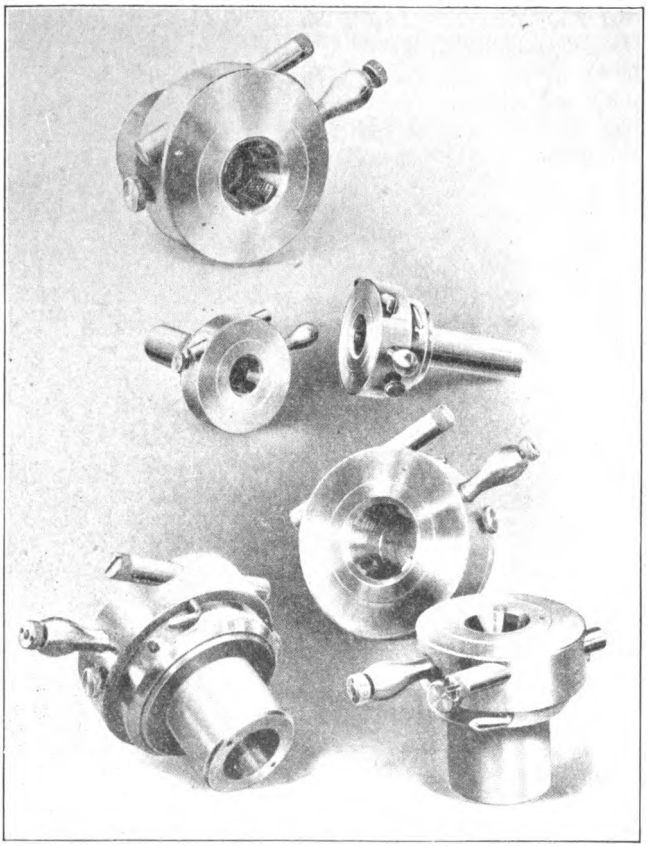


Fig. 123. Releasing Tap Holder

grade of machine steel possessing great stiffness and good wearing qualities. After roughing out to sizes somewhat larger than finish, the end which is to hold the tap may be turned to size, and the stem end, which is to run in the sleeve, fitted, after which the hole *I*, to receive the tap, may be made of a convenient size. In order that the hole may be perfectly concentric with the holder, it will be necessary to run the large end of the holder in the steady rest of the lathe; the opposite end should be fastened against the head center of the lathe in such a manner that the stem runs perfectly true. With work of this nature, the head center of the lathe must be in good condition and run true.

After the hole has been drilled somewhat smaller than finish size, it is necessary to true the hole with a boring tool; the hole should

be bored to within .010 inch of finish size, after which it may be reamed with a rose reamer. Before reaming, however, the outside edge of the hole should be chamfered to the shape of the point or cutting end of the reamer, to avoid any possibility of the reamer running. Some tool-makers never ream a hole of this nature if it can be avoided, always boring to size with a tool that makes a smooth cut. If extreme care is used and the holes are finished to size with a reamer, results good enough for a tool of this character may be obtained..



GROUP OF HARNESS AUTOMATIC DIES
Courtesy of Jones and Lamson Machine Company, Springfield, Vermont

TOOL-MAKING

PART II

STANDARD TOOLS

THREAD-CUTTING DIES

The size of a die is always denoted by the diameter of screw it will cut; a die that will cut a ½-inch screw is called a ½-inch die, irrespective of the outside diameter of the die itself.

Thread-cutting dies are made solid or adjustable. Solid dies are suitable for work that does not require extreme accuracy. They are comparatively inexpensive, and can be used to advantage as a roughing die when an adjustable die is used for finishing. Owing to the tendency of dies to change their sizes when hardened, and to the fact that there is no provision for wear, solid dies cannot be used where work must be made to gage. They are extensively employed in cutting threads on bolts, and for this class of work are made square, as shown in Fig. 124.

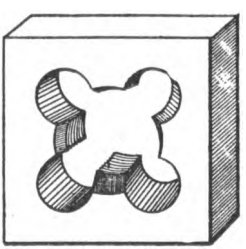


Fig. 124. Square Die

SOLID TYPE

Shaping Square Blank and Cutting Threads. In making a square die, the blank may be machined to thickness and to size on the square edges. One of the flat surfaces should be coated with blue vitriol, or the blank may be heated until it shows a distinct brown or blue color. The center may be found by scribing lines across corners, as shown in Fig. 125. It should be prickpunched at *A*, where the lines intersect. The die blank may be clamped to the faceplate of a lathe, and made to run true by means of the center indicator. If there is no tap of the proper size, and only one die is to be made, the thread may be cut with an inside threading tool, provided the hole is of sufficient size; if not, a tap must be made.

If the thread is cut with a threading tool, the size must be determined by means of a male gage, which may be a screw of the proper size.

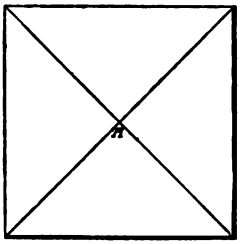


Fig. 125. Locating Center of Die Blank

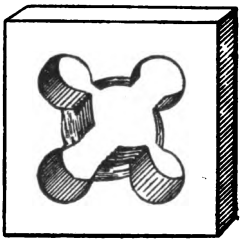


Fig. 126. Chamfered Die

Chamfering. After threading, the hole should be chamfered to a depth of three or four threads, the amount depending on the pitch of the thread, a fine pitch not requiring so many threads chamfered as a coarse pitch. The chamfering should not be much larger on the face of the die than the diameter of the screw to be cut. Figs. 126 and 127 show two views of a die chamfered and relieved on the cutting edges. The chamfering should be done with a countersink or taper reamer of the proper angle. In the absence of such a cutter, a tool held in the tool post of the lathe may be used.

Number of Cutting Edges. Most manufacturers making dies for the market give four cutting edges to all sizes up to and including 4 inches. When dies are made in the shop where they are to be used, custom varies. Some tool-makers advocate three cutting edges for all dies smaller than $\frac{1}{4}$ inch, and five or more cutting edges for dies above 2 inches. The objection to more cutting edges than are absolutely needed on large dies is the increase in the cost of making.

Fig. 127. Section Showing Chamfered Threads

When making dies for threading tubing, or for work where part of the circumference is cut away, it is better to give them a greater number of cutting edges than would otherwise be the case.

Rake of Cutting Edges. For general shop work, where the dies are to be used for all kinds of stock, it is advisable to make the cutting edges radial, as shown in Fig. 128, the cutting edges *AAAA* all pointing to the center. For brass castings, the cutting edges should have a slight negative rake, as shown

in Fig. 129, the cutting edges *AAAA* all pointing back of the center.

Clearance Holes. After threading and countersinking (chamfering), screw in a piece of steel threaded to fit the die, and face

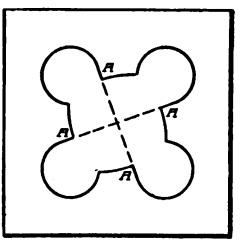


Fig. 128. Die with Radial Cutting Edges

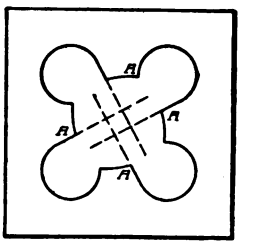


Fig. 129. Die with Threads Having Negative Rake

it off flush. Lay out the centers of the clearance holes on the back of the die, and drill a hole the size of the pilot of a counterbore whose body will cut the right size for the clearance hole. For dies from $\frac{3}{8}$ to $\frac{3}{4}$ inch in size and having four cutting edges, the centers of these holes may be the intersections of a circle, having a diameter equal to the diameter of the screw to be cut, with lines drawn across the corners, as shown in Fig. 130. Prickpunch these points. For a die having four clearance holes whose centers are laid out in this

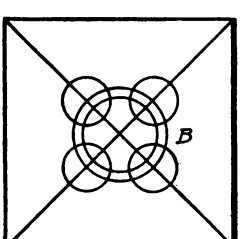


Fig. 130. Method of Laying Out Die Blank

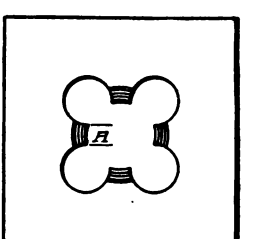


Fig. 131. Clearance Holes in Die Blank

way, it is customary to make the clearance holes one-half the size of the die; that is, clearance holes in a $\frac{1}{2}$-inch die would be $\frac{1}{4}$ inch. The width of the top of the lands *A*, Fig. 131, should be about $\frac{1}{16}$ of the circumference of the screw to be cut.

The diameter given for the clearance holes does not apply to dies smaller or larger than the sizes mentioned ($\frac{3}{8}$ to $\frac{3}{4}$ inch), especially if the dies are to be used in the screw machine, as the clearance holes not only provide a cutting edge, but also make a convenient place for the chips; if the holes are so small that the oil cannot wash the chips out, the chips clog the holes and tear the thread.

For small dies, the clearance holes are of a size that allows the chips to collect in the holes without tearing the threads, and they are located at a greater distance from the center of the die, in order to give sufficient strength to the lands. The desired shape and thickness may be given the sides of the lands by filing. When it is considered advisable that screw dies above $\frac{3}{4}$ inch have larger clearance holes than the size mentioned, the holes should be located at a distance from the center of the die that will give the desired thickness to the land.

Circular Dies. For screw-machine and turret-lathe work, dies are generally made circular; and as holders for dies are part of the equipment of every shop having screw machines, the dies should be made to fit these holders; but it is not considered good practice to make the diameter of dies less than $2\frac{1}{2}$ times the diameter of the screw to be cut, and the thickness of the die $1\frac{1}{4}$ times the diameter of the screw.

ADJUSTABLE TYPE

Method of Adjustment. While round dies for screw-machine work may be made solid for roughing out a thread that is to be finished

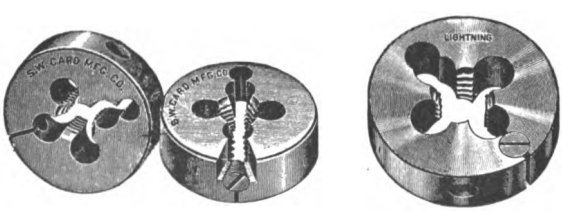


Fig. 132. Two Forms of Adjustable Dies. Left—Card Die with End Taper Screw; Right—Wiley and Russell Die with Side Taper Screw

by another die, the finish die should be made adjustable. When making adjustable dies, the general instructions given for solid dies may be followed, except that some provision must be made for

adjustment. This is done by splitting the dies at one side as shown at *A*, Fig. 133. In order that the die may not spring out of shape in hardening, it is advisable to cut the slot from the center of the die, leaving a thin margin as shown at *A*, Fig. 133; after the die is hardened, this may be cut away with a beveled emery wheel. If the thickness at *B* is too great to allow the die to close readily when adjusted to size, the hole may be drilled and connected with the clearance hole by means of a saw cut.

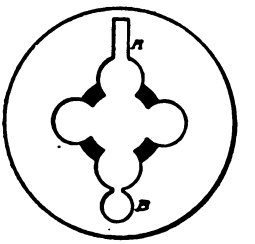


Fig. 133. Die Blank Showing Margins Left for Hardening

Die Holders. If many round dies of the same diameter are to be made, it is economical to have a holder with a shank which fits the hole in the spindle of the lathe; the opposite end should be made to receive the die blanks, which should be turned to fit the die holder in the screw machine. Fig. 134 shows the holder to be used in the lathe. *A* represents a die blank in the holder; *B* is the shank which fits in the spindle of the lathe; *C* is a recess in the hol ler to provide for the projection left on the blank when it is cut from the bar, and also to provide an opening to receive the drill and tap after they run through the die. After the blank is placed in the holder and secured in position by the

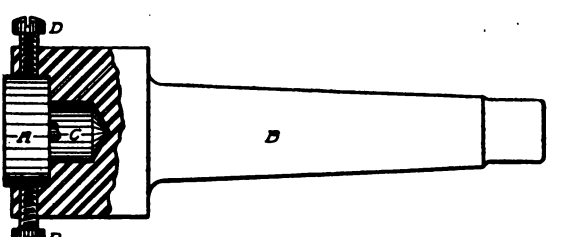


Fig. 134. Die Holder for Lathe

screw *D D*, the outer surface may be faced smooth and true with the circumference, after which the blank should be reversed and the opposite side finished to the proper thickness. The die is now ready to be drilled and tapped.

Drilling and Tapping. Before drilling, the die should be carefully centered in the lathe. To insure a full thread in the die, a drill a few thousandths of an inch smaller than tap size should be used, after which a reamer of the proper size may be run through. When tapping the thread, it is advisable to use two or three taps of different sizes; the finish tap should be the size of the desired hole in the die, and should be of the form known as screw die hob. Where several taps are used for a die, there should be some difference in the diameter so that any inequality in the shape or pitch of the thread may be removed by the larger tap; otherwise imperfect threads will result. For instance, if three taps are to be used for a ¼-inch die, the first one may be .230 inch in diameter; the second .240 inch in diameter, and the finish tap, if the die is to be solid, .250 inch in diameter. If it is to be an adjustable die, the finish tap should be .253 inch in diameter, in order to furnish clearance to the lands when it is closed to .250 inch.

Hardening and Tempering. *Carbon Steel.* Dies should be heated very slowly for hardening, either in an oven furnace, or in some receptacle that protects them from the action of the fire. When heated to a uniform low red, they may be immersed in a bath of lukewarm brine and worked back and forth to insure hardening the threads. The temper should be drawn to a full straw color. If it is an adjustable die, the portion marked *B*, Fig. 133, should be drawn to a blue color in order that it may spring without breaking. This is done by placing this portion of the die on a red-hot iron plate; or the jaws of a heavy pair of tongs may be heated red hot, and the die grasped in the tongs and held until the desired color appears. The blue color must not be allowed to extend to the threads, or they will be too soft. When the desired color has been obtained, the die may be dropped into oil to prevent drawing the temper more than is desired.

High-Speed Steel. A great many threading dies are made from high-speed steel. In order to secure the best results it is necessary to harden them properly. Tools having projecting portions that must retain their exact shape and size cannot be heated to so high a temperature as lathe and planer tools that are to be ground to shape after hardening.

Threading dies should never be hardened in a blast of air, as the oxygen in the air might attack the metal, oxidize the threads,

and so spoil the die. A furnace specially designed for such tools is shown in Fig. 22, Part I. The die may be suspended by means of a hook, or a specially designed holder in the center of the furnace. The flame circulating around the outside of the opening in the furnace leaves the center portion unaffected by the blast. When the tool has reached a temperature of 2150° F., it should be removed and immediately plunged into a bath of cottonseed oil and worked back and forth to force the oil through the opening. Threading dies should have their temper drawn to 490° F. in order to reduce the brittleness to a point where the cutting edges will stand up when in use.

Better results are achieved if the dies are pack hardened. Heat them to a yellow heat and allow them to remain at this temperature

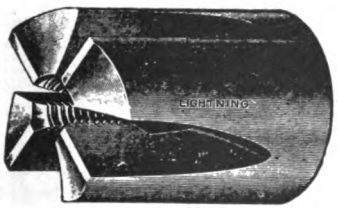


Fig. 135. Lightning Spring Die
Courtesy of Wiley and Russell Manufacturing Company Greenfield, Massachusetts

Fig. 136. Collar for Spring Die
Courtesy of Wiley and Russell Manufacturing Company, Greenfield, Massachusetts

for from one-half hour to one hour; then quench them in cottonseed oil. When cold, the temper may be drawn to 480° F.

Spring Screw-Threading Dies. This form of die, Fig. 135, is adjusted by means of a clamp collar as shown in Fig. 136. In some shops it is the only form of screw-threading die used for screw-machine work. When so used, it should be fitted to one of the holders on hand, provided there is one of the proper size.

Average dimensions of spring dies are given in Table V These sizes are used by a manufacturing concern employing a great many screw-threading dies of this description. It is not necessary to follow the proportions given, as they are intended only as a guide, and may be changed to suit circumstances.

For uniform and well-finished threads, two dies should be used, one for roughing, and one for finishing.

TABLE V

Dimensions of Spring Screw-Threading Dies

Size of Screw (in.)	Outside Diameter (in.)	Length (in.)
$\frac{1}{4}$ to $\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{2}$
$\frac{1}{4}$ to $\frac{3}{4}$	$\frac{3}{4}$	$1\frac{3}{4}$
$\frac{3}{4}$ to 1	1	2
$\frac{1}{2}$ to $\frac{3}{4}$	$1\frac{1}{4}$	$2\frac{1}{4}$
$\frac{3}{4}$ to 1	$1\frac{5}{8}$	$2\frac{3}{4}$
1 to $1\frac{1}{4}$	2	3
$1\frac{1}{4}$ to $1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$
$1\frac{1}{2}$ to 2	$3\frac{1}{4}$	4

Where many dies of a size are made, it is best to have a holder with a shank fitting the center hole of some lathe. The stock can be machined to size and cut to length. The clearance hole in the back of the die should be first drilled somewhat larger than the diameter of the screw to be cut. For dies up to and including $\frac{1}{8}$ inch, this excess in size should be $\frac{1}{32}$ inch; for dies $\frac{1}{8}$ to $\frac{1}{4}$ inch, it should be $\frac{3}{64}$ inch; for dies $\frac{1}{4}$ inch and over, it should be from $\frac{1}{16}$ to $\frac{1}{8}$ inch. After drilling the clearance hole, the die should be reversed in the holder, and drilled and tapped the same as a round die, using a hob to finish the threads to size.

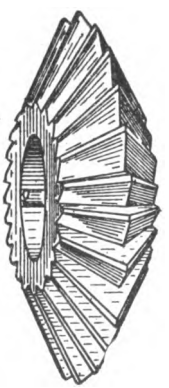


Fig. 137. Double Angle Milling Cutter

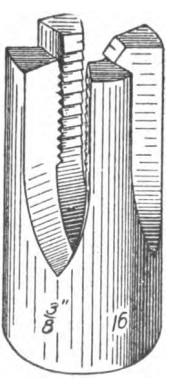


Fig. 138. Typical Stamping on Die

For general work, the die should have four cutting edges, making the lands about one-sixteenth the circumference of the screw to be cut. Chamfer about three threads. The length of the threaded portion of the die should not exceed one and one-quarter times the diameter of the screw to be cut. To produce the cutting edges, use a 45-degree double-angle milling cutter, Fig. 137, which should be of sufficiently large diameter to produce a cut, as shown in Fig. 138.

The chamfered edges should be relieved, and the cutting edges finished with a fine file. Stamp the size and number of threads on the back end of the die, as shown in Fig. 138, and then harden.

Hardening. The die should be heated in a tube and hardened in a jet of water coming up from the bottom of a tank, in order that the water may enter the threaded portion. The die should be hardened a little farther up than the length of the thread, and should be moved up and down in the bath to prevent a water line; the temper should be drawn to a full straw color.

Malleable Iron Collars. Where many clamp collars are used, castings of malleable iron or gun metal may be made from a pattern; the hole should be cored to within $\frac{1}{16}$ inch of finish size, drilled, and reamed. When the screw hole has been drilled and tapped and the collar split, it is ready to use. If the surfaces are finished, the cost is materially increased.

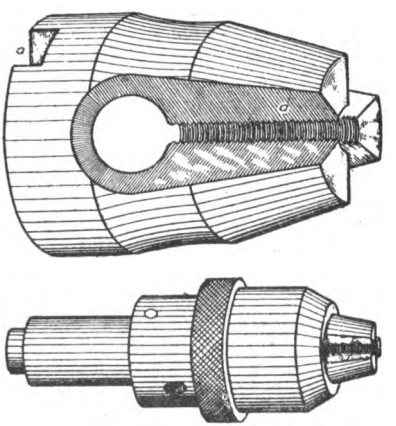


Fig. 139. Special Form of Spring Die

Illustration of Spring Die. The form of spring die shown in Fig. 139 is especially adapted for heavy work; the jaws, being heavy and well supported by the cap, do not spring when taking heavy cuts. One end of the cap has an internal thread which screws on to the end of the shank, thus drawing the cutting end of the tool securely against the shank. This also provides a means of adjusting the size of the cutting end, as the cap is tapered on the inside at the outer end to fit the taper on the outside of the jaws. A locking nut fastens the cap securely when it has been set to the right size. The cutting end of the die has grooves, as shown at *a*. These grooves engage with tongues on the shank to prevent turning.

Die Holders. When cutting threads in screw machines and turret lathes, dies are held in die holders, which are constructed in two parts, as shown in Fig. 140. The shank *A* fits the hole in the turret, while the die holder *B* has a stem that fits the hole in the shank. While the die is cutting, the pins *D* and *C* are engaged, and prevent the holder *B* from turning. When the turret slide of the screw machine has traveled to its limit, the holder is drawn out of the shank until the machine is reversed, when the pins engage on their opposite sides. A pin is put through the stem of the holder at *E;* this strikes the end of the shank just at the time the pins *D* and *C* become disengaged.

Shank. Both shank and body may be made of machinery steel; the shank may be finished to size, except the portion marked *A*,

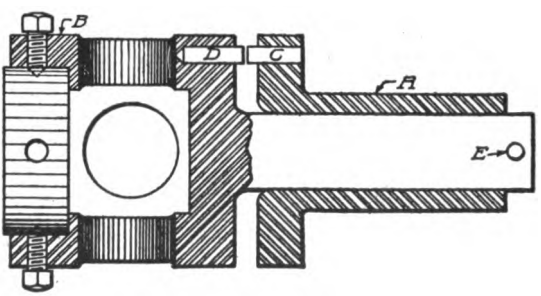


Fig. 140. Die Holder

which should be left .010 inch large for grinding. The front end of the hole should be rounded, as shown, to allow the fillet in the shoulder of the stem to enter. This fillet is left for strength. The pinhole should be drilled and reamed. When the holders are to take dies not over $\frac{1}{8}$ inch in size, this pinhole may be $\frac{3}{16}$ inch in diameter; for dies from $\frac{1}{8}$ to $\frac{5}{16}$ in size, the hole should be $\frac{1}{4}$ inch in diameter. As the dies increase in size, the pin must increase proportionately. The shank may be casehardened in a mixture of granulated charred leather and charcoal; it should run about two hours, and then be dipped in a bath of oil. The hole should be lapped straight and true, and the outside ground to fit the hole in the turret. The pin *C* should be of tool steel, hardened and drawn to a blue color, and forced into place.

Holder. The holder *B* may be made from a forging, or turned from a solid piece. After roughing to size somewhat larger than finish, the stem may be turned and fitted to the hole in the shank, in which it should turn freely. The larger portion, or body, is next turned to size. This should be run in the steady rest, and the end drilled and bored for the die and for clearance back of the die, as shown. Three or four large holes drilled into the clearance hole provide the chips and oil with a way of escape, thus preventing injury to the threads of a screw long enough to reach through the die when being threaded.

Screw Holes. Screw holes should be drilled and tapped as shown. The screws are to hold the die in position in the holder, and also to adjust to size dies that are split. The stem may be placed in the shank, and the pinhole transferred through the pinhole in the shank into the body; this should be done before the pin *C* is pressed into place. The pin *D* should be hardened the same as *C*. The pinhole for the pin *E* should be drilled in a location that allows *C* and *D* to become disengaged, and yet have no play between them.

COUNTERBORES

Two-Edged Flat Counterbores. Counterbores are tools used for enlarging a hole without changing its relative position. For an emergency job and for a small number of holes, it is advisable to make

Fig. 141 Flat Counterbore

as cheap a form as is consistent with the work to be done. Probably the cheapest counterbore that will do satisfactory work is the one shown in Fig. 141. This can be forged so as to require but little machine work. After forging, it is turned to size, and the shank *A* and pilot *B* finished with a fine file before being taken from the lathe. The cutting edges *CC* should be faced true and smooth. The necking between the pilot and the body should be cut with a tool having the corners slightly rounded, to decrease the liability to cracking when the counterbore is hardened. The flat sides *D* of the body

may be finish-filed; the edges should be drawfiled, and more stock removed on the back than on the cutting edge, to prevent binding. File the cutting edges for clearance, as shown at *E*. The pilot and the body should be hard the entire length, or they will wear and rough up so that they cannot cut a smooth hole. Draw the temper to a full straw color. Unless intended for accurate work, the tool need not be ground.

Counterbores with Four Cutting Edges. For permanent equipment, counterbores are usually made with four cutting edges, as shown in Fig. 142 and Fig. 143; Fig. 142 represents a taper-shank counterbore for a taper collet, while Fig. 143 has a straight shank to

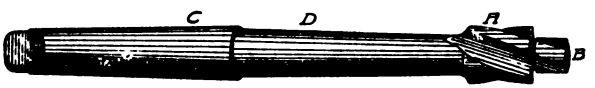


Fig. 142. Typical Counterbore with Taper Shank

Fig. 143. Typical Counterbore with Straight Shank

be used in a chuck or collet having a straight hole the size of the shank.

Counterbores for screw holes are usually made in sets of three —one for the head of the screw with pilot, or guide, of body size; one for the head with pilot of tap-drill size; and one to enlarge a tap-drill hole to body size.

Directions for Making. The following instructions apply to counterbores with either straight or taper shanks.

Turning to Size. Take stock somewhat larger than the finish size of the counterbore. Turn a roughing chip all over the piece; turn the necked portion between the shank and body to size, and stamp the size of counterbore and pilot as shown in Fig. 143; turn shank *C*, body *A*, and pilot *B* .015 to .020 inch above finish sizes to allow for grinding. In the case of the taper-shank counterbore the tenon should be milled.

Milling Grooves. The counterbore is now ready to have the grooves milled to form the cutting edges. One method is to cut

them with a right-hand spiral of from 10 degrees to 15 degrees; the other method is to cut the grooves straight. The former has the effect of running chips back from the cutting edges, and works very well on wrought iron and steel; while the latter method is considered more satisfactory for brass and cast iron, though it too works well

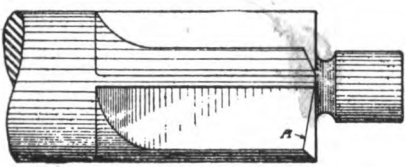


Fig. 144. Sketch Showing Clearance of Cutting Edges of Counterbore

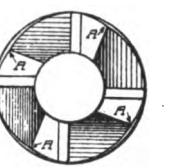


Fig. 145. Sketch Showing Clearance of Lands

on wrought iron and steel. The cutting edges are given clearance by filing, as shown at *A* in Fig. 144. If the counterbore is to be used for brass, it is necessary to give clearance to the lands also, as shown at *AAAA*, Fig. 145.

Centering. When centering counterbores, or any tools whose centers are not to be used after the tool is finished, the drill should be small, and the countersinking no larger than is necessary for good results in machining. If large centers should, by accident, be put in the ends, the one on the end to be hardened should be filled with fire clay moistened with water to the consistency of dough, or with graphite mixed with oil; this prevents steam from forming in the hole and cracking the tool when dipped in the bath. If the

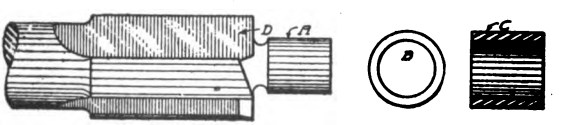


Fig. 146. Sleeve for Counterbores with Holes Larger than Pilot

piece is to be heated in lead, the filling should be dried thoroughly before immersing.

Use of Sleeve. Solid counterbores can be used with holes larger than the pilot by forcing a sleeve over it, as shown in Fig. 146. *B* and *C* are two views of the sleeve which is to be forced on to the pilot *A*.

Grinding. After hardening, the counterbore may be ground to size on the shank, body, and pilot; the shank should be ground first, as the length is greater, and, in the case of a counterbore having

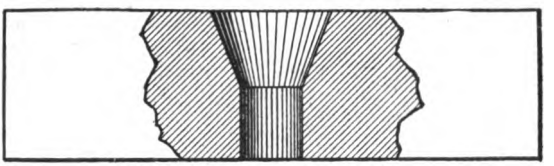


Fig. 147. Taper Hole in Line with Hole Already Drilled

a straight shank, the grinder may be adjusted to perfect alignment by measurement.

Two-lipped counterbores are sharpened by grinding on the flat faces marked *D*, Fig. 141; a four-lipped counterbore is ground on the flat side of the groove, as *D*, Fig. 146.

Counterbores for Special Cases. It is necessary many times to produce a hole of a given taper extending into a piece of work, as shown in Fig. 147, where the hole must be exactly in line with a drilled hole already in the piece. This can be done by using a counterbore of the design shown in Fig. 148. At other times, it is necessary to produce an impression of special form which must be true with a drilled hole. In such cases a counterbore may be made whose pilot is the size of the drilled hole, and whose body has the form of the desired impression, Fig. 149. As the cutting edges of this counterbore cannot be ground after hardening, they must first be backed off for clearance with files and scrapers, and special pains taken during the hardening to prevent springing. This can be done by heating the piece in a muffle furnace and turning it frequently to prevent uneven heating; or by placing the tool in a piece of gas pipe in an ordinary fire, quenching it in lukewarm water, and drawing the temper to a full straw color, 460° F. Better results follow if the tool is pack hardened, and then quenched in raw linseed oil or cottonseed oil.

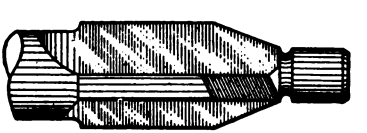


Fig. 148. Counterbore for Producing Holes Shown in Fig. 147

Facing Tool with Inserted Cutter. Where a limited number of holes are to be counterbored, the tool shown in Fig. 150 may be made. All that is necessary in making this tool is a piece of stock, *A*, the size of the hole to be counterbored, and a piece of drill rod for the cutter *B*; the latter is filed to a cutting edge, hardened, and driven into place.

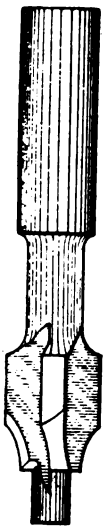
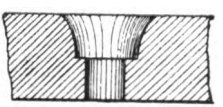


Fig. 149. Counterbore for Making Special Shaped Hole

If accuracy is essential, the piece of drill rod must be cut off somewhat longer than the diameter of the required hole; it should be driven into the hole in the bar leaving an equal length on each side, then turned to the correct diameter and filed to shape. If several cutters are to be used in the same bar, or if the tool is to be used as a facing bar to square a shoulder inside a piece of work, Fig. 151, the cutter *B* is removed from the bar; after the bar is in place, it is inserted and held by a set screw *C*.



Counterbores for Large Work. For large work, a counterbore may be made, as shown in Fig. 152, *A* being the cutter bar which should be made of tool steel $\frac{1}{16}$ to $\frac{1}{8}$ inch larger than finish size.

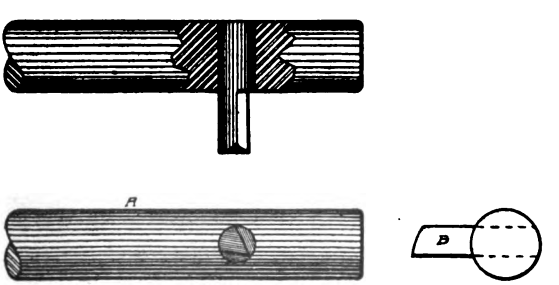


Fig 150 Facing Tool with Inserted Cutter

Cutting Slot. After taking a roughing chip, leaving the bar a trifle large, a slot should be made to receive the cutter *C*. This

is done by drilling a series of holes as shown in Fig. 153. After prick-punching the bar, it should be clamped to a drill-press table, and held in a pair of V-blocks. To insure the drill holes going through the center of the bar the prickpunched marks should be set as follows: Place the blade of a try square against one side of the bar; measure to the center; then place the square against the opposite side, and measure in the same manner. When the distance from the square blade to the centers is the same on each side, the piece is in the proper position for drilling The drill-press table may then be swung around until the prickpunched marks are in proper location with the spindle

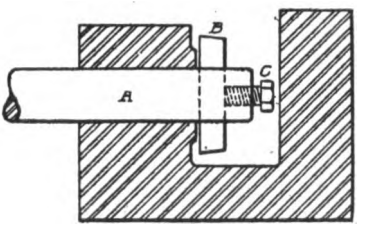


Fig. 151 Facing Bar

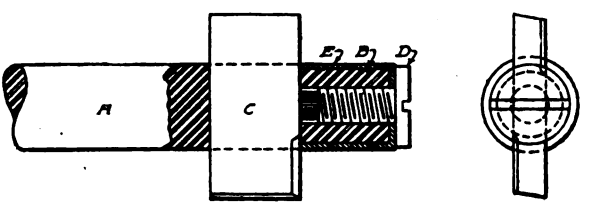


Fig 152 Typical Counterbore for Large Work

of the press. After drilling, a drift may be driven through to break the walls separating the holes, and the slot filed to size.

Fishtail Cutter. Where the necessary tools are to be obtained, there is a much more accurate and satisfactory method of producing the slot. It consists in cutting the slot from the solid with a fishtail cutter, Fig. 154. The piece of work is held on the centers of the dividing head; the cutter is fed into the stock, and the table moved to produce a slot of the right length, the operation being repeated until the slot is quite through the piece.

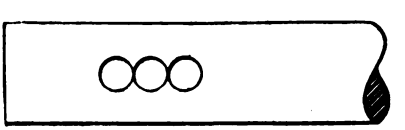


Fig 153. Making Slot for Cutter

When using this form of cutter take light cuts and fine feeds, and run the cutter at high speed, keeping it flooded with oil. Before starting, make sure that the cutter is well sharpened and that it has plenty of clearance at the edges to prevent deviation from a straight line. If conditions are right, this cutter will produce a straight, true slot in a fraction of the time necessary to drill and file it out. If it is essential to have the ends of the slot square, they must be filed or broached to shape after cutting.

This type of cutter is used very extensively in shops for building machines the spindles of which must be provided with slots to receive a center key used in driving shanked tools out of the spindles.

Finishing Tool. The bar, Fig. 152, should be placed with one end in the steady rest, and the other end strapped to the head center of the lathe. The screw hole in the end is now drilled and tapped into the slot, in order that the screw may bind the cutter. The

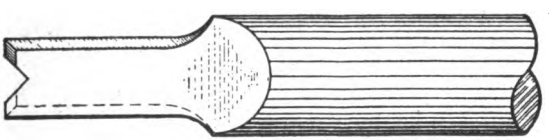


Fig. 151. Special Fishtail Cutter

end should be countersunk to provide a center for finish turning. The bar may be turned to size at *A*, and the pilot finished to size. The screw cap *D* should have a head $\frac{1}{16}$ inch larger than the part *B*, in order that it may hold the sleeve in place should the latter have a tendency to come off when removing the counterbore from the hole. The cutter *C* should be a close fit in the slot. A headless screw should be made short, so that it will not interfere with the dead center of the lathe when it is screwed to place against the cutter blank. It is intended to be used when turning the cutter to the right diameter and should be kept for that purpose.

Counterbores with Inserted Pilots. These are useful when the counterbores need frequent sharpening, or when holes of a variety of sizes are to be counterbored to the same size. A common form of counterbore having an inserted pilot is shown in Fig. 155.

Drilling and Turning to Size. When making this counterbore, the stock should have a roughing chip taken off, and the hole *E*

drilled part way from the shank end. This drilling may be done in the speed lathe, the drill being held in a chuck in the head spindle, the center in the opposite end of the piece should be on the dead

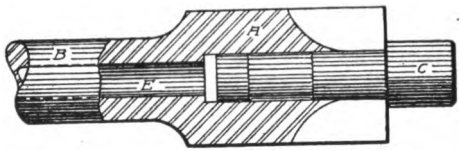


Fig 155. Counterbore with Inserted Pilot

center of the lathe. If the piece is turned a one-half revolution occasionally, the drill will cut accurately enough, as perfect alignment is not necessary in this hole, since it is intended only for use when driving out the pilot.

After drilling, the shank end should be carefully countersunk The piece is now ready to be turned to grinding size, which should be from .015 to .020 inch oversize. After the outside has been turned, the hole for the pilot is drilled and bored, the large end of the counterbore running in the steady rest.

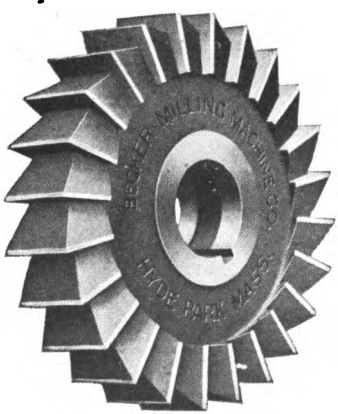


Fig. 156. Special Milling Cutter for Counterbores
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

Cutting Edges. The counterbore should have four cutting edges for all ordinary work; these may be made with a side milling cutter the face of which is sufficiently wide to cover the width of tooth. The form of cutter is shown in Fig. 156, while an end view of the teeth of the counterbore is shown in Fig. 157. When milling the teeth, the counterbore can best be held in the chuck on the spiral head. If a more stubbed form of tooth is needed than the one shown in Fig. 155, the spiral head may be tipped to

the desired angle and the cutter fed through the counterbore, instead of sunk into it.

Hardening. After milling, the burrs should be removed, and the counterbore stamped and hardened. To harden, it should be heated to a red nearly the whole length of body; when dipped in the bath, it should be inverted in order that the teeth may be uppermost; it should be worked up and down rapidly in the bath until the red has entirely disappeared, and allowed to remain until cold. If the counterbore is larger than 1 inch in diameter, the strain must be removed immediately after removing from the bath by heating the piece over the fire, as already explained.

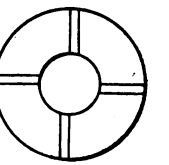


Fig 157. End View of Teeth of Counterbore

The pilot should be turned, as shown in Fig. 158. *A* and *BB* should be left about .010 inch large for grinding after hardening; *C* should be turned $\frac{1}{32}$ inch smaller than the hole in the mill, as this does not bear when the pilot is in place. A slight depression should be made between the head and the first bearing point *B* for the emery wheel to pass over in grinding *A* is the only part that needs to be hard, but, unless a piece of tube is slipped over the stem *B* when the pilot is put in the bath, it will be almost impossible to harden *A* the entire length and leave *B* soft. As *A* is likely to rough up when used, it is best to harden a short distance on the stem *B*, unless there should be a great difference in size between *A* and *B*. In the

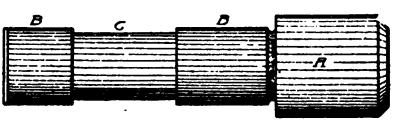


Fig 158. Pilot for Counterbore

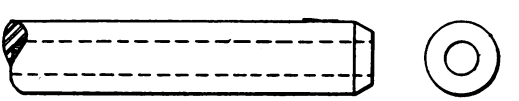


Fig 159 Cover for Pilot When Hardening

latter case a tube, or a piece of iron with a hole drilled in the end the size of *B* and having the end beveled, as shown in Fig. 159, should be slipped over *B* when the pilot is heated. The cover should be slipped over the stem and up against the shoulder of the head to

prevent a water line, if this precaution is taken, there is no danger of the pilot cracking under the head.

Grinding. After hardening and tempering, the pilot is ground to size at *A*, and the portions *BB* are ground to fit the hole of the counterbore. After grinding, the pilot is forced into place The counterbore may be ground with the pilot in position. When the counterbore is dull the pilot should be forced out of it, and the cutting edges ground with an emery wheel.

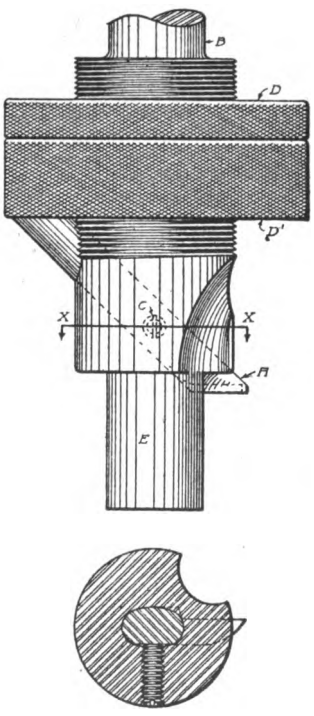


Fig 160 Single-Edged Adjustable Counterbore

Counterbores with Single-Edged Adjustable Cutter. A very satisfactory form of adjustable counterbore that works well where a tool with but one cutting edge is needed, is shown in Fig. 160. This tool has a rather wide range of adjustment, and can be made at a nominal cost.

The cutter *A* may be made from carbon tool steel or high-speed steel, according to the use to which it is to be put, it is placed at an angle of 45 degrees with the shank axis. The cutter is adjustable to position and locked by the knurled nuts *DD* and bound by the set screw *C*. The pilot *E* may be used in holes of various sizes by providing sleeves the holes of which fit the pilot and the diameters of which fit the holes to receive them. The shank *B* may be straight or tapering according to the custom in the individual shop.

This form of counterbore is sometimes provided with a rectangular-shaped cutter instead of the round one shown. When this

is desirable, the rectangular-shaped hole to receive it may be produced with a fishtail cutter, described on page 108. In the case of the counterbore under consideration, however, it would be necessary to turn the swivel table of the milling machine to give the desired angle.

The fishtail cutter will produce a hole with rounded ends. If this is objectionable, the ends may be filed square or may be squared with a broach. For the general run of work, however, the rounded ends are not objectionable. In fact, for the majority of jobs a round cutter in a round hole, as shown in the cut, would answer as well as one made rectangular in form, and could be made for a fraction of the cost.

Combination Counterbores. These are used when it is necessary to change the size of counterbore and pilot frequently. A shank or bar is made to accommodate different sizes of cutters, and sleeves serve as pilots. In Fig. 161, *A* is the cutter, and *B* the pilot which is tapped in the end to receive a screw to hold the sleeves, and *C* is the shank which is held in a chuck or collet when the counterbore is in use.

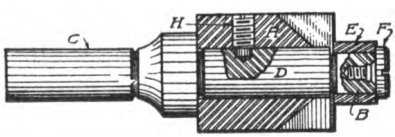


Fig. 161. Combination Counterbore

After taking a roughing chip off the bar, the end *B* is run in the steady rest and the hole for the screw *F* is drilled and tapped. The outside end is countersunk to a 60-degree angle to run on a center. When machining the holder, the portions *B*, *C*, and *D* should be left about .010 inch larger than finish size, to allow for grinding; if more convenient, however, they may be left a few thousandths of an inch above size, and filed to finish dimensions.

The body, or cutter, *A*, should have a hole $\frac{1}{16}$ inch smaller than finish size drilled through it; the outside surface should be turned off, and the piece annealed. If a grinder having an internal grinding attachment is at hand, the hole in the cutter should be left .005 inch small for grinding. If the worker does not have the tool, the hole may be reamed to finish size. The outside diameter should be left about .010 inch large; the ends should be faced to length, and the teeth cut. If four teeth are to be cut, the work may be done with the

side milling cutter, shown in Fig. 156. The counterbore should be held in a chuck on the spiral head spindle, which should be tipped to produce a strong tooth, as shown in Fig. 161. Before hardening, the hole should be drilled and tapped for the screw *H*, which holds the counterbore to the bar.

To harden, the counterbore should be given an even, low, red heat, and plunged into water or brine in such a manner that the bath will come in contact with the teeth. If the teeth are stubbed and strong, the temper need not be drawn more than to a light straw color.

The screw *H* should be made of tool steel and have a projection $\frac{1}{8}$ inch long on one end, turned to the bottom of the thread. This is to enter a hole drilled in the bar or holder and keep the counterbore from turning. The end of the screw should be about .005 inch smaller than the hole. The screw should be hardened and drawn to a blue color. The sleeve intended to go on the pilot *E* should be made of tool steel, hardened, and ground to size inside and out. The screw *F* may be made of machine steel, casehardened to the proper depth, by heating it to a red and sprinkling with powdered cyanide of potassium, then reheating and plunging it into water.

HOLLOW MILLS

Hollow mills are used in screw machines and turret lathes for roughing down and finishing. They are also used in drill-press work for finishing a projection which must be in some given position; in the latter case, they are generally guided by a bushing in a fixture, to bring the projection into the proper location.

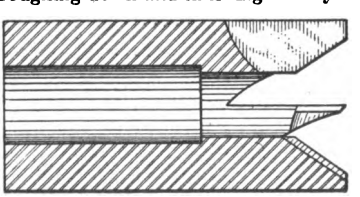


Fig. 162. Hollow Mill with V-End

Plain Hollow Mills. For roughing out work on a screw machine or turret lathe, solid mills having strong stubbed teeth are preferred because of their rigidity. For finishing, they are made adjustable in order to get exact sizes. Fig. 162 shows a plain hollow mill having the cutting end hollowed out in the form of a V, in order that it may center itself when starting to cut. Fig. 163 shows a form of plain hollow mill intended for

use in squaring up a shoulder at the end of a cut that has been made with a mill of the form shown in Fig. 162, or it may be used for roughing out a piece, but it will not center itself so readily as the

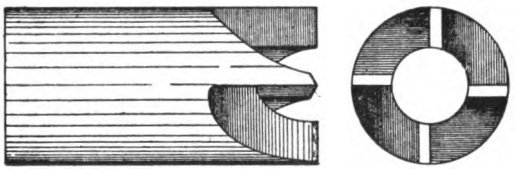


Fig 163. Hollow Mill for Squaring Up Shoulder

former one. For small hollow mills, some tool-makers advise three cutting teeth, while ot ers conte d t at better results re secured with four teeth on *all* sizes.

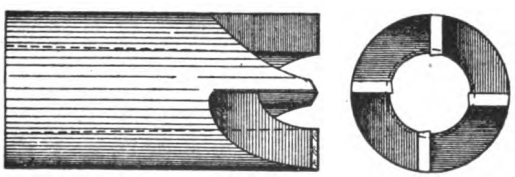


Fig. 164. Hollow Mill with Tapered Hole

Boring and Reaming. The rear end of the mill is bored somewhat larger than the cutting end, to allow it to clear on long cuts. The cutting end must be relieved, or it will bind and rough the work and probably twist it off in the mill. There are several methods of relieving mills; the most common one is to ream the hole tapering, making it larger at the back end, as shown in Fig. 164. Another method is to file back of the edges, as shown in Fig. 165.

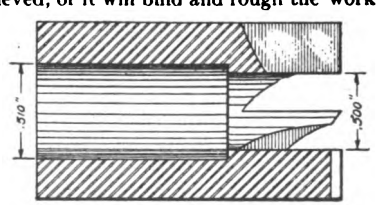


Fig 165 Hollow Mill with Edges Filed

Use of Mill Holder. For making several hollow mills having the same outside diameter, it is advisable to use a holder of the form

shown in Fig. 166, which has a taper shank that fits the spindle of a lathe. The hole in the other end of the holder should be the size of the holder in the screw machine or turret lathe, which holds the mills when in use. The steel for the hollow mills should be cut to

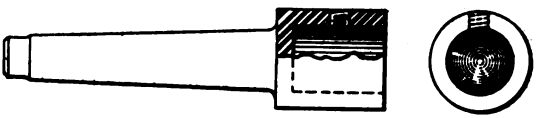


Fig. 166. Holder for Hollow Mills

length, and turned to the proper diameter to fit the holder. After putting the blank in the holder, the ends may be squared, and the holes drilled and bored to the desired sizes. If the mill is to be one of the forms shown in Figs. 162, 163, and 164, the cutting end may be reamed with a taper reamer to give the necessary clearance. The reamer should be run in from the back end in order that this end may be larger. For the form shown in Fig. 164, the hole at the cutting end should be straight and of finish size.

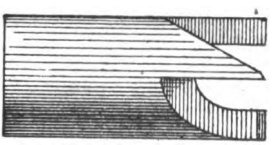


Fig. 167 Mill with a Strong Tooth

Cutting Teeth. The mill is now ready for cutting the teeth. If four cutting edges are to be given, a side milling cutter may be used, of a diameter about double the diameter of the hollow mill to be cut. The blank should be held in a chuck on the end of the spindle in the spiral head. For a strong tooth, the spiral head should be set at an angle that will produce the tooth shown in Fig. 167, by feeding the milling cutter *through* the blank. If a deeper tooth is desired, the spiral head must be set so that the blank will be in a vertical position, and the milling cutter fed in until the desired form and depth of tooth are obtained.

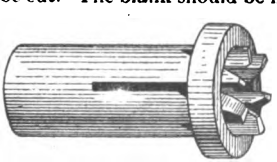


Fig. 168. Adjustable Mill

Adjustable Hollow Mills. These may be made by following the instructions given for plain hollow mills, except that the mill must be split, Fig. 168, to allow for alteration in size.

Methods of Adjustment. There are two methods of adjusting the mill. In one the outside of the cutting end of the mill is tapered, and a collar having a corresponding taper hole is forced on the mill. The collar closes it, and causes it to make a smaller cut. The other method is to turn the outside of the hollow mill straight, and close by means of a clamp collar, Fig. 169.

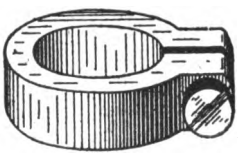


Fig. 169. Clamp Collar

Cutting Teeth. As adjustable hollow mills are generally used for finishing cuts, and not when taking heavy cuts, the teeth may be made finer than those of solid mills used for roughing. The teeth, being nearer together, will finish a cylindrical piece more accurately than if the teeth were cut farther apart. It is customary to give adjustable hollow mills which are to be used for finishing, from six to eight teeth. The cutting edges should be radial for most work. Better results will be obtained if the hole in the cutting end of the mill is left .005 inch small, and ground to size after the mill is hardened.

Hardening and Grinding Hollow Mills. The hollow mill, whether it be solid or adjustable, should be hardened a trifle farther

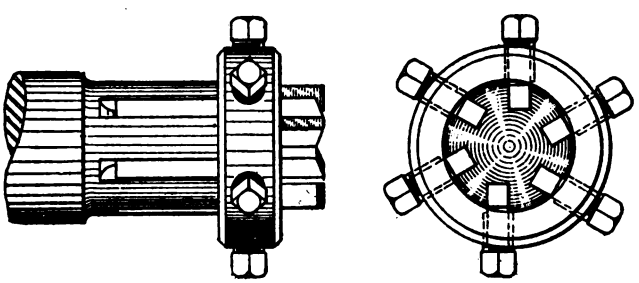


Fig. 170. Hollow Mill with Removable Blades

up than the length of the teeth, and drawn to a straw color. The mill is sharpened by grinding on the ends of the teeth.

Hollow Mills with Inserted Blades. For large work, hollow mills are made with inserted blades. The type shown in Fig. 170 does good service on rough work. The blades of this mill may be made of self-

hardening steel and inserted in a machine-steel body; the grooves in the body, to receive the blades, should be milled with a cutter whose thickness corresponds to the size of the steel to be used for the blades. The grooves are cut somewhat deeper at the front end of the holder, n order that the blades may have clearance to prevent binding. The edge of the slot corresponding to the cutting edge of the blade should be radial.

Two collars should be made of machine steel, with holes sufficiently large to allow their being placed on the mill when the blades are in the slots. Each collar should be provided with the same number of set screws as there are blades in the mill. One collar holds the blades in the holder, while the other is placed nearly at the ends of the blades to support them while cutting. This form of mill is used on cuts not exceeding one inch in length, as the blades must project beyond the holder to the length of the cut.

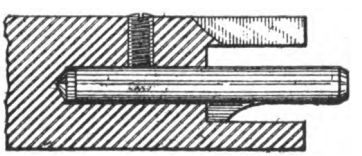


Fig. 171. Hollow Mill with Pilot

The size of cut may be changed somewhat by setting the cutters back or ahead in the slots, or paper may be placed in the slots under the blades to increase the diameter of the cut. The blades are set to an even length by bringing them against a surface perpendicular to the axis of the body of the tool.

Hollow Mills with Pilot. It is often desirable to mill the outside of a projection central with a hole passing through it. This may be done very satisfactorily with a hollow mill having a pilot, as shown in Fig. 171. It is advisable to hold the pilot in place by means of a set screw. In order to give clearance to the teeth to prevent the mill binding when cutting, the hole may be bored tapering, .010 inch in $\frac{1}{2}$ inch of length, making it largest at the back end.

When hardening a mill of this description, it is advisable to dip it into the bath with the cutting end uppermost, working it up and down rapidly. After being hardened, it should be drawn to a straw color. The pilot should be turned .010 inch above finish size, hardened, drawn to a brown color, and ground to the desired dimensions.

At times it is necessary, or desirable, to use a hollow mill as a counterbore; that is, it is necessary to enlarge a hole all the way

through a piece of stock. As the core removed would bind and stick in the hole in the mill, the hole is made eccentric, Fig. 172. The pilot is concentric with the outside, and should not be a tight

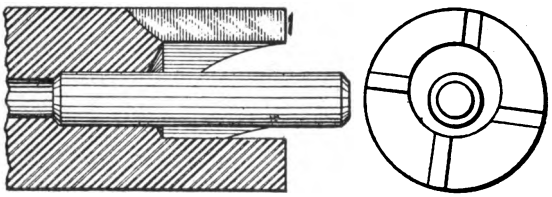


Fig. 172. Hollow Mill with Eccentric Pilot

fit in the hole to be enlarged. The core removed will be smaller than the hole in the mill, and consequently will not bind.

FORMING TOOLS

Forming tools are used when several pieces are to be made of exactly the same shape. They are particularly valuable for giving the desired shape to formed mills and similar tools, and in duplicating a given shape on work produced in the screw machine.

Forming tools are made flat and circular in shape. When used in the lathe for shaping such tools as milling machine cutters, they are generally made flat; for backing off formed milling machine cutters, they are always made flat; for screw machines in duplicating a given shape, they are made both flat and circular.

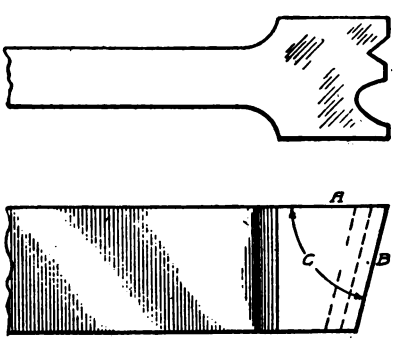


Fig. 173. Flat Forming Tool

Flat Forming Tools. The flat forming tool is made as a solid cutter, the tool and shank being in one piece, Fig. 173, or the cutter and shank may be made separate, Fig. 174. When but one forming

tool is to be made, the former will be found to be inexpensive; but for making many tools, it will be much cheaper to adopt the latter.

Holders. On certain classes of work, it is advisable to use a forming tool on a holder of the kind shown in Fig. 175, which is known as a *spring holder*. On account of its design, it may spring somewhat when used on heavy cuts, thus reducing the tendency to chatter. It is necessary to make these holders of tool steel, giving them a spring temper at the point marked *A*. The slot *B* allows the forming blade *D* to spring away from the work when under heavy strain. The blades may be planed up in long strips and cut off the required length. The tongue *E* should fit the slot *C*, which, with two cap screws through *F* and *G*, securely holds the blade in position.

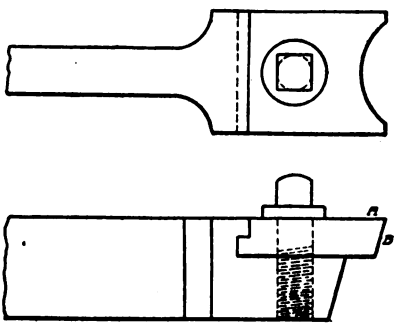


Fig. 171. Forming Tool with Separate Shank

Clearance. In order that a forming tool may cut readily, it is necessary to give the surface marked *B*, Fig. 174, a sufficient amount of clearance. For tools to be used for shaping milling machine cutters and similar tools, a clearance of from 10 degrees to 15 degrees will

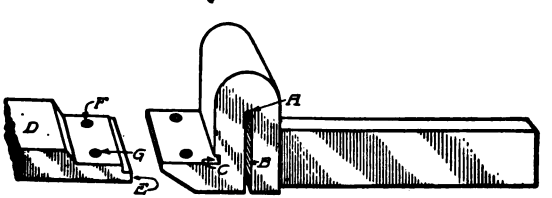


Fig. 175. Spring Forming Tool Holder

be ample; that is, the angle should be from 80 degrees to 75 degrees. But if the tool is to be used for backing off the teeth of formed milling machine cutters, it is necessary to give a clearance of from 18 degrees to 22 degrees. When making a forming tool having the

required angle at *B*, the shape can be produced by tipping the blank to the correct angle and planing or milling with a tool having exactly the desired shape. The tool used may be made of a shape enough different from that desired as to produce the proper shape when the cutter is in a vertical position, and the blank at a given angle from that position, as shown in Fig. 176. Or the tool may be held in the tool post (or in a fixture made for the purpose) of the shaper or planer at the same angle as the blank being cut, Fig. 177, and it will produce a shape corresponding very closely to its own.

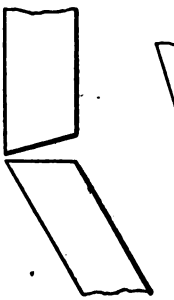


Fig. 176. Tool with Cutter Vertical

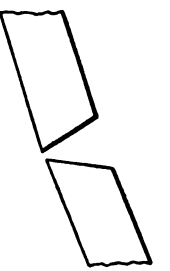


Fig. 177. Tool with Cutter at an Angle

Screw-Machine Forming Tools. In screw-machine and similar work for duplicating given shapes, a forming tool is made like the one shown in Fig. 178. *A* represents a holder used by the Brown and Sharpe Manufacturing Company for use on their screw machines;

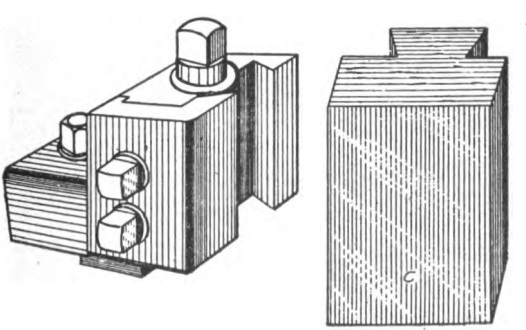


Fig. 178. Forming Tool for Duplicating Shapes

B shows the forming tool blank; and the desired shape is cut in the surface marked *C*.

Circular Forming Tools. These are used very extensively on screw-machine and similar work. They are valuable on account

of the ease with which any number of them can be produced, provided a forming tool is used in producing the shape on the face, as shown in Fig. 179.

Milling Cutting Edges. After the blank has been given the proper shape, it may be milled as shown in Fig. 180, in order to provide a cutting edge. If it is desired to produce a shape on the piece being machined, to correspond with the shape of a tool, it is necessary to have the cutting edge radial, Fig. 180. In order to feed the tool into the stock faster than can be done with the form shown, it is given more clearance, Fig. 181. On a tool whose cutting edge is not radial and will not produce a shape corresponding to its own, it is necessary when cutting the edge with the rake shown in Fig. 181, to make the face of the tool slightly different in form from that desired.

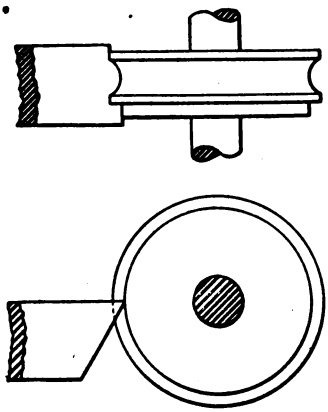


Fig. 179. Straight Forming Tool for Producing Circular Tool

Preventing Cracks. After the cutting edge has been milled, the name or number of the tool should be stamped on it, and it is then ready for hardening. When extremely high carbon steel is used, the tools sometimes crack while hardening from the strain incident to their shape. Some toolmakers overcome this tendency by making two extra cuts in the edge, Fig. 182.

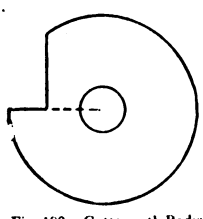


Fig. 180. Cutter with Radial Cutting Edge

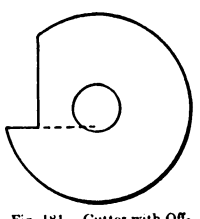


Fig. 181. Cutter with Offset Cutting Edge

Lessening Need for Grinding. Two cutting edges, Fig. 183, are often given a tool, in order that it may not need to be ground so often as when it has but one cutting edge. It is not necessary to stop

the screw machine nearly so long to grind both cutting edges, as to stop the machine twice to grind the same edge, on account of the time necessary to rig up the grinder.

Hardening. To harden, the tool should be heated to a low red, and plunged into a bath of water or brine from which the chill has been removed; it should be worked around well in the bath. If the temper is not to be drawn after hardening, the tool may be held over the fire after removal from the bath, and heated sufficiently to remove the tendency to crack from internal strains.

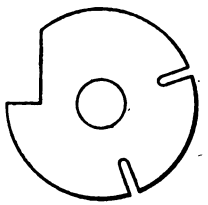


Fig. 182. Cutter with Cuts to Prevent Contraction Cracks

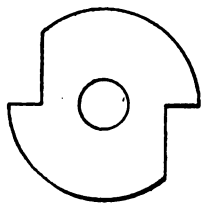


Fig. 183. Cutter with Double Cutting Edge

Tempering. On account of some weak projection, which, because of its shape, is likely to break when used, it is sometimes necessary to draw the temper. It is not always necessary to draw the temper to a straw color, and as a light straw is the first temper color visible, some other means must be employed. The tool may be placed in a kettle of oil, and with the aid of a thermometer the desired degree of heat may be accurately obtained. The writer recalls a

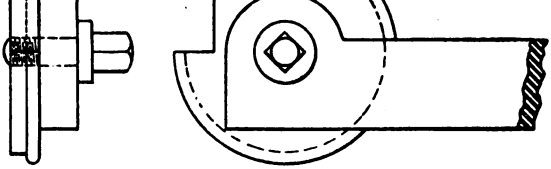


Fig. 184. Tool Holder for Hand Screw Machines

certain forming tool which was too brittle when left as it came from the hardening bath, yet was not hard enough when drawn to even the faintest straw color. After removing from the hardening bath, it was placed in a kettle of boiling water and left about five minutes.

The heat of the water at 212 degrees reduced the brittleness so that the tool stood up in good shape, yet was not perceptibly softened.

The following is an excellent plan: A bath of water having about one inch of oil on top is made ready; the tool, after being heated red hot, is plunged down through the oil into the water. Enough oil adheres to prevent the sudden shock which the steel would receive if plunged directly into cold water. Pack hardening also gives excellent results.

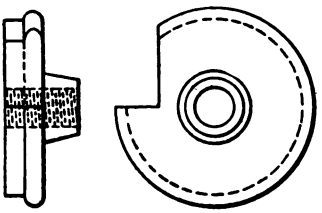


Fig. 185. Cutting Tool for Heavy Cuts

Tool Holders. The form of the holder for the tool depends on the class of work to be done and the machine in which it is to be used. Fig. 184 shows a design commonly used for hand screw-machine work. If the cuts are comparatively light, the side of the tool and holder may be flat, as shown. If, however, heavy cuts are taken which would have a tendency to turn the tool, the latter is often made with a taper projection on one side, Fig. 185, the holder having

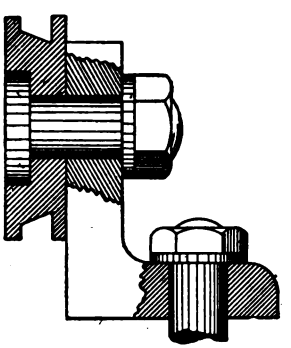


Fig. 186. Holder for Automatic Screw Machine

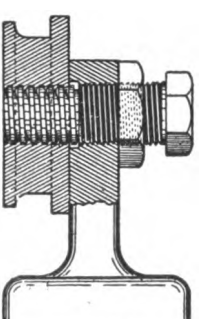


Fig. 187. Holder for Heavy Cuts on Automatic Machine

a corresponding taper hole to receive the projection. This projection should be a good fit in the taper hole, but should not go in far enough to strike the bottom; neither should the side of the tool bear against the side of the holder.

When used in automatic screw machines, the holder is generally of a different shape from that used for hand screw machines. A very common form is illustrated in Fig. 186. This holder is made in the form of an angle iron, and is fastened to the tool rest by means of the bolt shown. The tool is secured to the upright side of the holder by the bolt, with its head let into the forming tool.

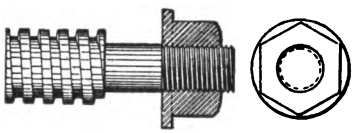


Fig 188. Adapting Bolt

When extra heavy cuts are to be taken with a forming tool, it is sometimes considered advisable to make a holder of the form shown in Fig. 187 The holder is bolted to the tool rest in the same manner as the one represented in Fig. 186. A square thread having a pitch of five or six threads to the inch is cut in the forming tool. The thread should be a right- or left-hand one, depending on which side of the machine the tool is to be located, the thread being such that the tool will tighten by the pressure exerted by the cut. To get an adjustment, the thread in the holder must be of a finer pitch than that in the forming tool, and of the same hand. This tool can, if desired, be employed in the ordinary form of holder shown in Fig. 186, by the use of the bolt shown in Fig. 188.

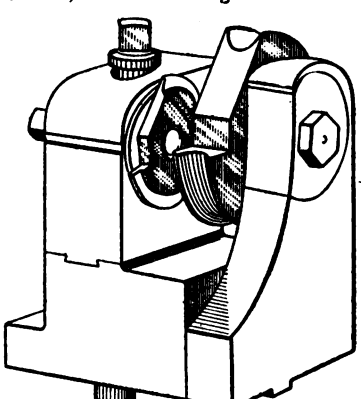


Fig 189. Arrangement of Two Forming Tools for Special Work

At times, it is necessary to use two forming tools; these may be arranged to meet the requirements of the individual job. In Fig. 189 are shown two forming tools arranged to cut a desired shape.

High-Speed Steel Forming Tools. At the present time, when high-speed steel is so extensively used in reducing the cost of many machine operations, forming tools are also made from this metal. The high-speed steel tools may be hardened by heating them in

specially constructed furnaces, or in a crucible of red-hot lead, and then dipping them in oil, but more satisfactory results are obtained if they are pack hardened by the method already described.

After pack hardening the tool, it may be necessary to draw the temper somewhat; this will not be needed if the tool is strong and is not to be subjected to severe use. If, however, the tool is weak or has weak projections, it will be found necessary.

MILLING CUTTERS

Milling machine cutters are made in two different forms—*solid* and *with inserted teeth*. It is customary in most shops to make cutters up to 6 or 8 inches in diameter solid, and above this size with inserted teeth.

Use of High-Speed Steel. At the present time, when rapid reduction of stock is necessary, it is the custom in many shops to

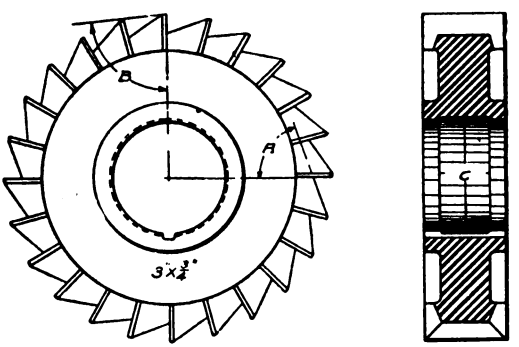


Fig. 190. Side View and Section of Side Milling Cutter

make many of the milling machine cutters from high-speed steel. If this steel is properly annealed, it is easily worked to shape; but much better results are obtained if the tools used in cutting it, both in the lathe and milling machine, are made from high-speed steel.

High-speed steel milling cutters may be heated for hardening in the specially designed furnace shown in Fig. 23, Part I; but if so treated, they must first be pre-heated in an ordinary fire to a low red heat, as the sudden expansion due to rapid heating would rupture the steel and spoil a valuable tool. When uniformly heated to the

TABLE VI

Cutting Edges for Milling Cutters

Diameter of Cutter (in.)	No. of Cutting Edges	Diameter of Cutter (in.)	No. of Cutting Edges
¼	6	2½	20
½	8	3	24
1	10 or 12	3½	26
1¼	14	4	28
1½	16	5	30
2	18	6	32

proper temperature, they should be plunged into raw linseed oil or cottonseed oil. Here again, as in the case of forming tools, much more satisfactory results are obtained if the cutters are pack hardened.

Although many shops have adopted high-speed steel for most of their milling cutters, and some shops use nothing else, yet many mechanics claim that for cutters of intricate form which must retain a fine finishing edge, high-carbon steel gives better results. But if they use the latter steel for such cutters, yet for all roughing cutters and for those of ordinary form where fineness of cutting edge is not material, they use high-speed steel.

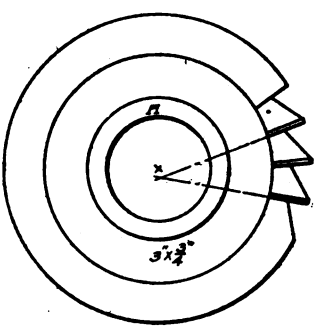


Fig. 191. Diagram of Cutter with Negative Rake

Solid Straight Cutters. When making solid cutters, it is advisable to use steel somewhat larger than the finish diameter of the cutter. A hole should be drilled in the blank $\frac{1}{16}$ inch smaller than the finish size of the hole, and the outside surface turned off. After annealing, the blank should be put in the chuck on the lathe, the hole bored, reamed to size, and recessed as shown at *C* in the sectional view of Fig. 190. The piece should then be placed on the mandrel and turned to the proper diameter and length.

Milling Teeth. The teeth should be cut in the universal milling machine, or in a milling machine provided with a pair of index centers. The number of cutting edges for solid milling cutters varies some-

what according to the nature of the work to be done, but for general shop use the numbers estimated in Table VI will be found satisfactory:

For most work it is desirable to have the faces of the teeth radial, Fig. 190. However, when milling cutters are made to run in the direction of the feed or on to the work instead of against it, the teeth should be given a negative rake (cut ahead of the center), as shown in Fig. 191, as this has a tendency to keep the piece being milled from drawing toward the cutters. For cutters to be used in sinking a semicircular slot in such a piece of work as is shown in Fig. 192, the teeth should be cut *back* of the center.

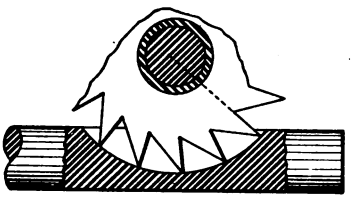


Fig. 192. Form of Cutter for Semicircular Slot

When cutting the teeth, it is necessary to use a cutter that gives sufficient depth of tooth to provide a receptacle for chips, and also gives a form that supports the cutting edges. A cutter may be used that will produce an angle of about 50 degrees between the face and the back of the tooth, as shown at *A* in Fig. 190. The cutter should cut deep enough to leave the lands about $\frac{1}{32}$ inch in width at the cutting edges.

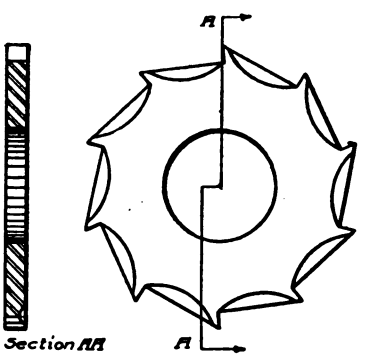


Fig. 193. Form of Cutter Used for Copper

Saws for Copper Work. Metal slitting saws for use on copper do not work well if made the same as those used on steel and most other metals. The face of the tool should have a rake of from 8 to 12 degrees, and the sides of the tool given clearance, as shown in Fig. 193. As such saws are usually made thicker at the circumference than toward the center hole, there is little trouble from their binding the work.

The pitch of saws for use on copper should be considerably coarser than for those used on the harder metals. For saws of

ordinary size, the teeth should be spaced nearly or quite 1 inch apart; for instance, a saw 4 inches in diameter should have 12 teeth.

Grinding the Hole to Size. It is customary to ream the holes in milling cutters to size, and if the cutter contracts in hardening, the holes are brought to size again by lapping with a lead or cast-iron lap, by means of oil and emery. This operation does not, however, provide for the enlarging of the hole. While expansion is an unusual occurrence, it does sometimes happen, and, as a con-

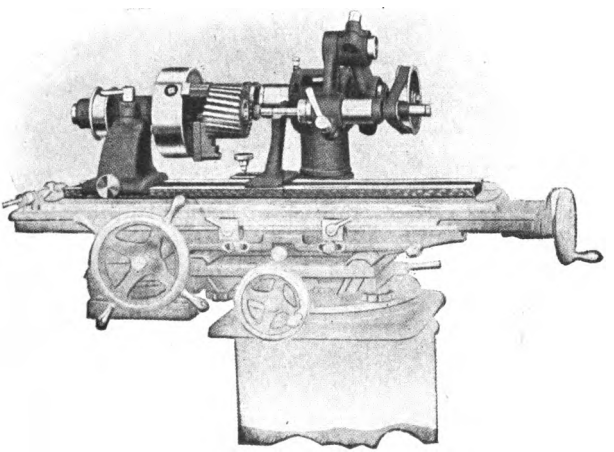


Fig. 194. Typical Set Up for Grinding a Cutter
Courtesy of Norton Grinding Company, Worcester, Massachusetts

sequence, the cutter does not fit the milling machine arbor and cannot do as good or as much work as it should.

The necessity of having a correct fit on the milling machine arbor makes it advisable to ream the hole of the cutter with a reamer about .005 inch under the size of the arbor, and to finish by grinding after the cutter is hardened. When grinding the hole to size, the cutter may be held in a chuck and ground with a small emery wheel, using the internal grinding attachment as shown in Fig. 194. This attachment is so designed that it may be swung out of the way when gaging the size of the hole, Fig. 195.

Grinding Shoulders. After grinding the hole to size, it is advisable to grind the shoulders on each side of the cutter, straight and true with the hole, in order to prevent any possibility of springing the milling machine arbor because of untrueness on the part of the cutter, and to prevent any possibility of the cutter running out of true. The shoulder, or boss, referred to is shown in *A*, Fig. 190.

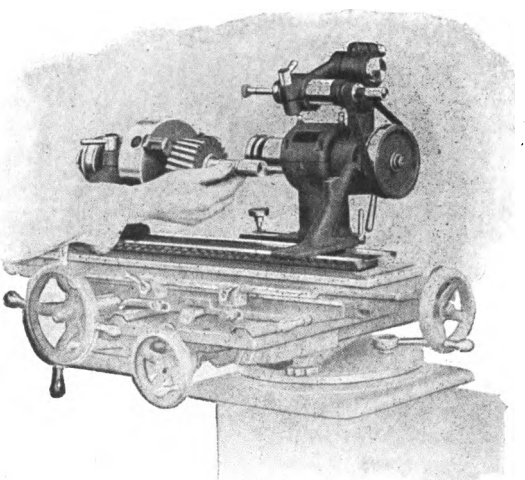


Fig. 195. Gaging Size of Hole in Cutter after Grinding
Courtesy of Norton Grinding Company, Worcester, Massachusetts

There are two methods of grinding the shoulders. By one method, the outer shoulder and the hole are ground at the same setting; if this is done properly, this shoulder will be true with the hole. The chuck is then removed from the grinder, and a faceplate having an expanding plug is put in its place. The shoulder that has been ground is placed against the faceplate, with the expanding plug in the hole of the cutter. The other shoulder may be ground after the plug is expanded until the cutter is held rigidly in place against the faceplate, which should run perfectly true.

By the other method, both shoulders are ground while on an arbor, which is necked down each side of the cutter, Fig. 196.

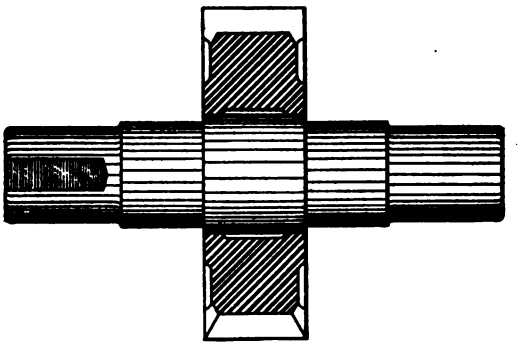


Fig. 196. Cutter Blank on Special Arbor for Grinding

Allowing the wheel to traverse the whole length of the shoulder but not cut into the arbor, as when an ordinary mandrel is used.

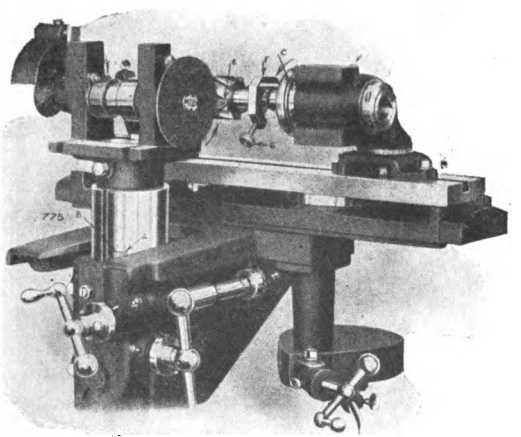


Fig. 197. Cutter in Position for Grinding Teeth
Courtesy of Cincinnati Milling Machine Company, Cincinnati, Ohio

Grinding Teeth. In order to get the best results from a milling cutter, it is necessary to use a form of grinder having some means of

properly locating each tooth as it is presented to the wheel. The usual arrangement is a finger adjustable to the proper height to produce the required amount of clearance, which is about 3 degrees, as shown at *B*, Fig. 190. With this amount of clearance, the cutter works freely and retains its edge; if more clearance is given, the cutter is likely to chatter, and the edges of the teeth will become dull rapidly.

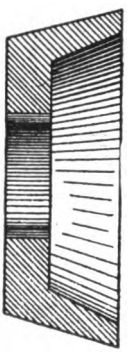


Fig. 198. Section of Cup Grinding Wheel

Fig. 197 shows a cutter in position for grinding the teeth; it will readily be seen that the tooth being ground rests on the centering gage *E*, which can be adjusted to give any desired amount of clearance to the tooth. For grinding the teeth on the side of a milling cutter, a small emery wheel may be used in order to get the necessary amount of clearance without touching the tooth next to the one being ground.

If a grinder is used which will take a cup wheel, Fig. 198, and whose table can be turned to bring the cutter in the position shown in Fig. 199, a form of clearance is given which is more satisfactory than a clearance ground with a small wheel. With the cup wheel the line of clearance is straight, while with the small plain wheel it is hollowed out, and as a consequence the cutting edge is weak.

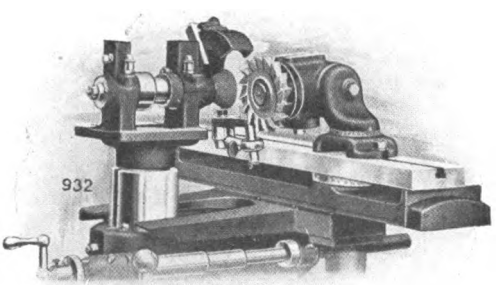


Fig. 199. Grinding Milling Cutter with Cup Wheel
Courtesy of Cincinnati Milling Machine Company, Cincinnati, Ohio

Side Milling Cutter. *Cutting Teeth.* The form of cutter shown in Fig. 190 is known as a side milling cutter. When cutting teeth on the sides, it is necessary to put the cutter on a plug whose upper

end does not project much above the top face of the cutter; this plug may be made straight and held in the chuck on the end of spindle in the spiral head. Such a plug is shown in Fig. 200, inserted in the cutter. If many cutters are made with teeth on the sides, it is advisable to make an expanding arbor, Fig. 201, whose shank fits the taper hole in the spindle of the spiral head. When milling the teeth on the sides, the index head must be inclined a little so that the side of the mill will stand at a small angle from the horizontal, in order that the lands of the teeth may be of equal width at each end. The amount of this inclination cannot readily be computed. It is formed by cutting first one tooth, leaving the cut somewhat shallow, then turning to the next tooth. After cutting the second tooth, the change in inclination will be apparent.

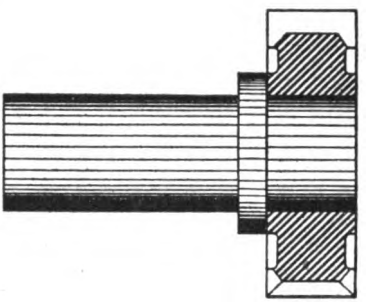


Fig. 200 Milling Cutter Mounted on Plug

Hardening. When the teeth are cut and the burrs removed, the diameter and length of the cutters may be stamped as shown in Fig. 190. The cutter is now ready for hardening. To harden successfully, it is necessary to have a low, uniform red heat; the teeth must be no hotter than the portion between the hole and the bottom of the teeth. If held toward the light, there should be no trace of black in the interior of the cutter. When a uniform heat, no higher than is necessary to harden the steel, has been obtained, the cutter should

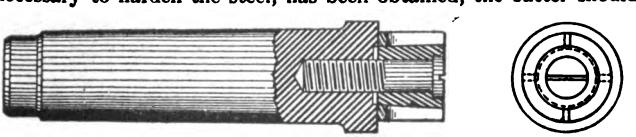


Fig. 201. Typical Expanding Arbor

be plunged into brine from which the chill has been removed, and worked around rapidly in the bath until the singing has ceased. It should then be removed from the brine and immediately plunged into oil and allowed to remain there until cold. When cold, the

cutter should be taken from the oil and heated sufficiently to prevent cracking from internal strains, then brightened, and the temper drawn to a straw color.

Spiral Milling Cutters. It is customary in most machine shops to make all milling cutters of more than ½-inch face with teeth cut spirally as in Fig. 202. The amount of spiral given the teeth varies in different shops and on different classes of work.

The object of spiral teeth is to maintain a uniformity of cutting duty at each instant of time. With teeth parallel to the cutter axis, the tooth, on meeting the work, takes the cut its entire length at the same instant, and the springing of the device holding the work and of the cutter arbor causes a jump to the work. If the teeth are

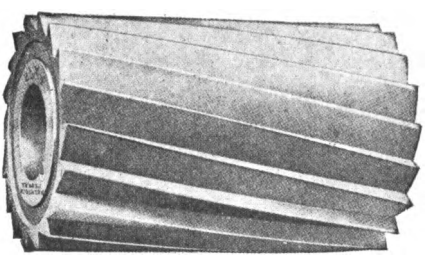


Fig. 202. Milling Cutter with Spiral Teeth
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

cut spirally, the cut proceeds gradually along the whole length of the tooth; and after it is started, a uniform cutting action is maintained, producing smoother work and a truer surface, especially in the case of wide cuts.

Milling cutters may be cut with either a right- or a left-hand spiral or helix, although it is generally considered good practice to cut a mill having a wide face with a spiral that will tend to force the cutter arbor into the spindle rather than to draw it out; then, again, it is better to have the cutting action force the solid shoulder against the box, rather than draw the adjusting nut against the box.

Where two very long mills are used on the same arbor and it is found necessary to cut them with a quick spiral, one cutter is sometimes made with a right-hand spiral and the other with a left-hand

spiral, in order to equalize the strain and to reduce the friction resulting from the shoulder of the spindle pressing hard against the box.

Special care should be taken in cutting spiral milling cutters to see that the work does not slip. When a cut has been taken across the face of a cutter, it is best to lower the knee of the milling machine, thus dropping the work away from the mill while coming back for another cut; the knee can then be raised to its proper position, which is determined by means of the graduated collar on the elevating shaft of the machine.

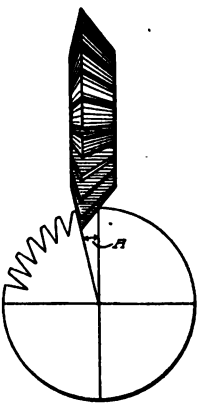


Fig. 203. Angular Cutter for Spiral Mill

As it is important that the face of the cutting tooth be radial and straight, it will be found necessary to use an angular cutter of the form shown in Fig. 203, since cutters of this form readily clear the radial face of the cut and so remain sharp longer and produce a smoother surface to the face of the tooth than an angular cutter of the form used for cutting teeth which are parallel to the cutter axis.

The angular cutters for spiral mills are made with either 40 degrees, 48 degrees, or 53 degrees on one side, and 12 degrees on the other. By setting the cutter, as shown in Fig. 203, so that the distance A is one-twelfth the diameter, the face cut by the 12-degree side of the angular cutter will be nearly radial for the usual proportions. The setting for cutting the teeth of a spiral cutter must be made before turning the spiral bed to the angle of the spiral.

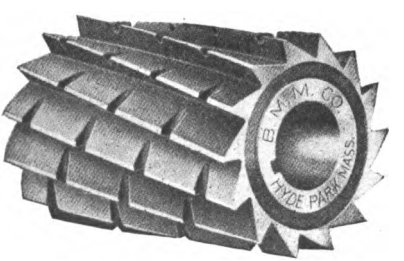


Fig. 204. Spiral Cutter with Nicked Teeth
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

Nicked Teeth. Spiral cutters with nicked teeth, Fig. 204, are especially adapted for heavy milling. As the chip is broken up, a

much heavier cut can be taken than would be possible with an ordinary cutter. The nicking may be done as follows: An engine lathe is geared to cut a thread of the required pitch—two threads to the inch will be found satisfactory—and with a round-nosed tool ⅛ inch wide, a thread is cut of a depth that will not grind out before the teeth become too shallow to allow further grinding. This thread should be cut before milling the spaces to form the teeth.

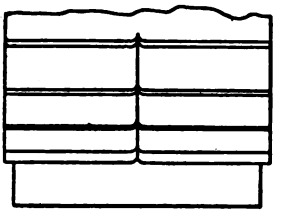


Fig. 205. Badly Made Mill

Milling Cutters with Interlocking Teeth. When two milling cutters of an equal diameter are to be used on the same arbor in such a manner that the end of one cutter is against the end of the other, the corners of the cutting teeth are likely to break away, leaving a projection—or fin—on the work, as shown in Fig. 205. In order to overcome this, part of the teeth are cut away on the sides of the cutters; that is, a tooth is cut away on one cutter, and the corresponding tooth on the other cutter is left full length to set into the recess formed by the cutting away of the tooth. In some shops it is customary to cut away every other tooth; while in others, two, three, or four teeth will be cut away and an equal number left. Fig. 206 represents a pair of mills having every other tooth cut away, while Fig. 207 represents a pair having four teeth cut away.

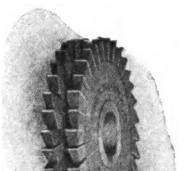


Fig. 206. Pair of Mills with Alternate Teeth Cut Away
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

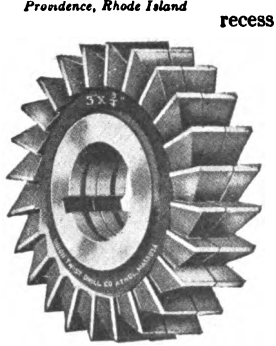


Fig. 207. Interlocking Cutters with Four Teeth Cut Away
Courtesy of Union Twist Drill Company, Athol, Massachusetts

In order to cut away the teeth to make a cutter with interlocking teeth, the cutter should be placed on a plug or an expanding arbor, as described for milling teeth on the sides of side milling cutters. By means of a milling

cutter having the proper width, the teeth may be milled away, although, in the case of a cutter having several teeth cut away, Fig. 207, it is well to use a narrow cutter, and after taking one cut, to turn the index head so that the next tooth is in position. This should be continued until the desired number of teeth have been cut away, after which the index head should be turned to pass over the required number of teeth, and the operation repeated.

It is necessary, when making cutters with interlocking teeth (sometimes called *dodged teeth*) that the milling be deep enough to prevent the corresponding tooth on the other part of the cutter from striking the bottom of the recess. The parts of the cutter should bear against each other on the shoulders, or hubs.

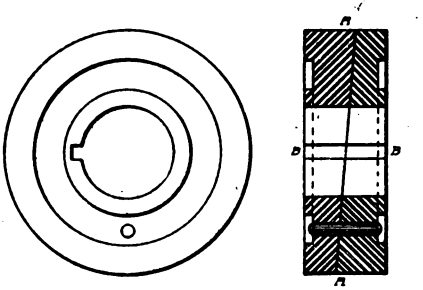


Fig. 208. Milling Cutter for Slots

Cutters for Milling Slots. An excellent form of cutter to be used for such work as milling slots can be made as shown in Fig. 208. This form is less expensive than one having interlocking teeth and answers the purpose as well. It is necesssary to make an eccentric mandrel of the design shown in Fig. 209, having the eccentric centers on opposite sides of the regular centers. The two pieces which make the cutter should be cut from the bar long enough to finish the thickness of the heaviest part

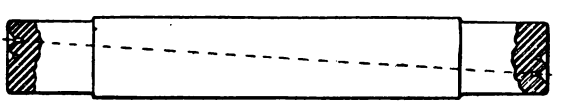


Fig. 209. Eccentric Mandrel for Slot Cutters

AA, Fig. 208. The hole is made $\frac{1}{16}$ inch smaller than finish size, the outside surface turned off, and the pieces annealed.

After annealing, the hole is made the size desired for grinding. One of the pieces is then placed on the eccentric mandrel, forced on until the side that is to be beveled is exactly in the center of the mandrel. The side *B* may be machined with the mandrel

running on the regular centers, while the beveled side must be machined with the mandrel running on the eccentric centers. When the arbor is running on these centers, a distance half-way between

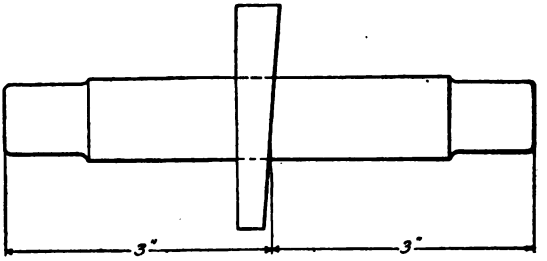


Fig. 210. Location of Cutter on Eccentric Mandrel

the two ends runs true; it is at this point that the side of the blank to receive the bevel should be located, as shown in Fig. 210, provided the eccentric centers are of an equal depth. When the two parts of the cutter have been machined to shape, they should be so placed on a stud that the two beveled sides will be next each other, Fig. 208, the thinnest part of one next to the thickest part of the other. The pinhole should now be drilled and reamed for a $\frac{3}{16}$-inch pin, which

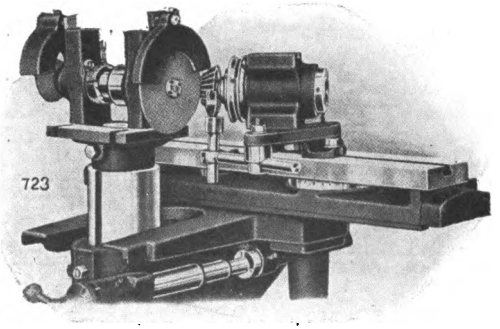


Fig. 211. Grinding an Angular Cutter
Courtesy of Cincinnati Milling Machine Company, Cincinnati, Ohio

should be inserted. The blank is next placed in the vise on the shaper or planer, and the spline slot cut as shown. It is now ready to be milled.

After the cutter has been hardened, the beveled sides are ground true, the halves put together, the hole ground to size, the cutter ground to thickness, and the teeth ground for clearance. If it is found necessary to increase the width of the slot, that can be done by shimming between the two parts of the cutter with paper or thin sheet metal; the design of the cutter allows this to be done without leaving any fin in the slot.

Angular Cutters. Directions for making angular cutters are practically the same as those given for making solid straight cutters, except that the desired angle must be given.

When milling the spaces which form the teeth, the index head is set at an angle that will cut the edge of the tooth of an equal width its entire length. After removing the burrs, the cutter may be hardened and tempered. The hole should be ground to size and the sides ground true with the hole. It should then be placed on a mandrel or stud, and the teeth ground for clearance Fig. 211 shows the method used in grinding the teeth of a mill of this form.

Fig. 212 Brown and Sharpe Inserted-Tooth Straight Cutter

Milling Cutters with Inserted Teeth. When milling cutters exceed 6 or 8 inches in diameter, it is generally cheaper to make the body of cast iron or machine steel, and to insert in the periphery teeth made of tool steel or high-speed steel. There are a variety of methods for holding the teeth in place. If the cutter is narrow, or is to be used as a side milling cutter, the grooves to receive the teeth may be cut straight (parallel to the cutter axis), Fig. 212. If the cutter face is over one inch long, the slots to receive the teeth should be cut in such a manner that spiral teeth may be used, as shown in Fig. 213.

Fig. 213. Spiral Cutter with Inserted Teeth
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

Giving Rake to Slots. While it is a comparatively easy matter to cut the slots spirally, it is difficult to make the teeth of a shape that will fit the spiral slots without the aid of special tools. Consequently, the slots are generally milled at an angle to the cutter axis, having the side

that corresponds to the face of the tooth equidistant from a radial line at each end of the cut. The face of the slot at one end would be ahead of the center, while at the opposite end it would be behind the center; this gives *front rake* and *negative rake*, respectively.

The slots should be cut somewhat wider than would be necessary were the teeth to be of spiral form. After turning to size, the faces of the teeth may be milled spirally to make them radial If the mills are intended for heavy work, the teeth should be nicked. The coarse-pitch thread should be cut before the teeth are milled spirally.

Fig. 214. Special Type of Inserted-Tooth Milling Cutter
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

Grinding Teeth. After being hardened, the teeth may be put in place and fastened, when they are ready for grinding. The emery wheel for grinding milling machine cutter teeth should be of the proper grade as to hardness and coarseness; if the wheel is very hard or fine, it will be likely to draw the temper at the cutting edges of the teeth; the emery should not be coarser than No. 60, or finer than No. 90.

If the face of the wheel is glazed, remove the glaze with a piece of emery wheel somewhat harder than the wheel in use; this not only removes the glaze, but makes the surface of the wheel more open and less likely to glaze. The emery wheel should run true; its face should not exceed $\frac{1}{4}$ inch in width. Generally speaking, the softer the emery wheel, the faster it should run, but the peripheral speed should not exceed 5,000 feet per minute.

Fastening Teeth. There are several methods for fastening the teeth in this form of cutter, any one of which gives satisfaction if the work is well done. The method illustrated in Fig. 214 is in use in the works of the Pratt and Whitney Company, and of the

Becker Milling Machine Company. In this design, between every second pair of teeth a hole is drilled and reamed taper to receive the taper pin, after which the slots are cut with a thin cutter. When the cutters are in place, the taper pins are driven into the holes, thus locking the cutters. To remove the cutters, the pins are driven out.

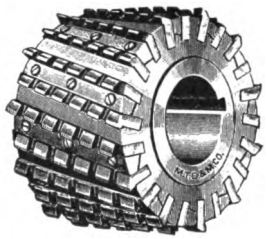


Fig. 215. Special Form of Inserted-Tooth Cutter
Courtesy of Morse Twist Drill and Machine Company, New Bedford, Massachusetts

A method of fastening cutters used by the Morse Twist Drill and Machine Company, of New Bedford, Massachusetts, is shown in Fig. 215. In this case the stock between every second pair of teeth is milled away, not so deep, however, as the slots for the cutters. Wedge-shaped pieces of steel are fitted between the teeth as shown. When these are drawn to place by means of fillister head screws, they bind the cutters very securely. If the wedge-shaped binding blocks touch the bottoms of the slots, they will not hold the cutters securely in place.

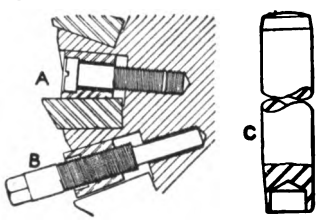


Fig. 216. Method of Fastening and Withdrawing Teeth Used by Brown and Sharpe Manufacturing Company

The cutter shown in Fig. 213 indicates the method used by the Brown and Sharpe Manufacturing Company. The teeth are securely held by taper bushings, which are drawn to place by screws, as shown at *A*, Fig. 216. To remove the taper bushings the screw A is removed and a plug *B* inserted. To insert a tooth, set blade in position and drive bushing into place using set *C*; then insert screws *A*.

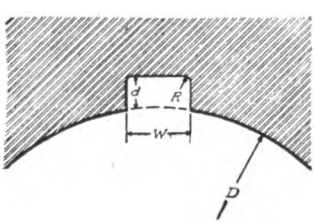


Fig. 217 Section of Standard Keyway

Keyways. To prevent milling machine cutters from turning on the arbor when cutting, it is necessary, especially when taking heavy cuts, to have keyways cut as shown in Fig. 217 and Table VII.

TABLE VII

Dimensions of Standard Keyways for Cutters

(Letters refer to Fig. 217)

Diameter (D) (in.)	Width (W) (in.)	Depth (d) (in.)	Radius (R) (in.)
$\frac{1}{2}$ to $\frac{9}{16}$	$\frac{3}{32}$	$\frac{3}{64}$	020
$\frac{5}{8}$ to $\frac{7}{8}$	$\frac{1}{8}$	$\frac{1}{16}$	030
$\frac{15}{16}$ to $1\frac{1}{8}$	$\frac{5}{32}$	$\frac{5}{64}$	035
$1\frac{3}{16}$ to $1\frac{3}{8}$	$\frac{3}{16}$	$\frac{3}{32}$	040
$1\frac{7}{16}$ to $1\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{8}$	050
$1\frac{11}{16}$ to 2	$\frac{5}{16}$	$\frac{5}{32}$	060
$2\frac{1}{16}$ to $2\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{16}$	060
$2\frac{9}{16}$ to 3	$\frac{7}{16}$	$\frac{3}{16}$	060

The arbor, of course, must have a similar slot to receive the key. It will be noticed that the dimension d refers to the diameter of the hole in the cutter, and not to the diameter of the cutter. A key-seating machine equipped with the proper tools, furnishes a very satisfactory method of cutting keyways in milling machine cutters, but all shops are not provided with such machines. The form of tool shown in Fig. 218 (A) is extensively used for such purposes on the planer, or shaper, and works well if everything about the machine is in good condition. If, however, there is any looseness in any of the parts, or any backlash in the vertical feed screw, the form Fig. 218 (B) will be found more satisfactory, as it is fed *up* in the operation of cutting, and the backlash cannot prove a source of annoyance. The writer has found this form of tool satisfactory on all interior cutting on the shaper and planer It is necessary to clamp the tool head so that it cannot rise on the return motion of the planer

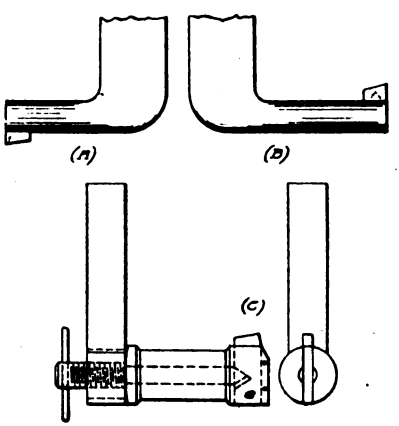


Fig. 218. Forms of Keyway Cutters for Planer or Shaper

In shops where many cutters having holes of the same size are made, a saving of time will be effected, if there is a draw-broaching machine, by broaching the keyway. A number of cutters having the same size of arbor hole can be broached in a fraction of the time necessary to cut them on the planer or shaper with the key-slotting tool shown; when, however, but one cutter is to have the keyway cut, the planer method may prove to be quicker.

As all stock is not perfectly homogeneous, tools of the description shown will not always cut an absolutely straight slot. For most purposes, the amount of variation need not be considered; but when an absolutely straight cut is necessary, the form of tool shown in

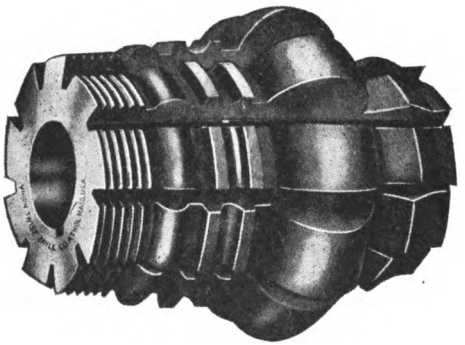


Fig. 219. Special Formed Cutter
Courtesy of Union Twist Drill Company, Athol, Massachusetts

Fig. 218 (*c*), is used. The portion marked *e* is made .001 or .002 inch smaller than the hole through which it is to pass. The cutter is set in a slot which passes through the tool as shown, and is fed into the work by means of the pointed feed screw.

Formed Cutters. As used by the Brown and Sharpe Manufacturing Company, the term formed cutter applies to cutters with teeth so relieved that they can be sharpened by grinding without changing their form. The term can be applied, however, to any cutter which cuts a form, regardless of the manner in which the teeth may be relieved. Fig. 219 represents a formed cutter. Formed cutters are used in many shops where work of irregular shape is milled in large quantities, as in sewing machine, gun, bicycle, and automobile shops.

If many formed mills are to be made, it is advisable to procure or make a machine specially designed for relieving—backing off—the teeth. As such machines are heavy and rigid, large cutters may be relieved and a smooth cut obtained, which is not possible with a light machine.

Backing-Off Lathe Attachments. Although this style of cutter can be made to better advantage in a shop equipped with machinery designed especially for this class of work, an ordinary engine lathe

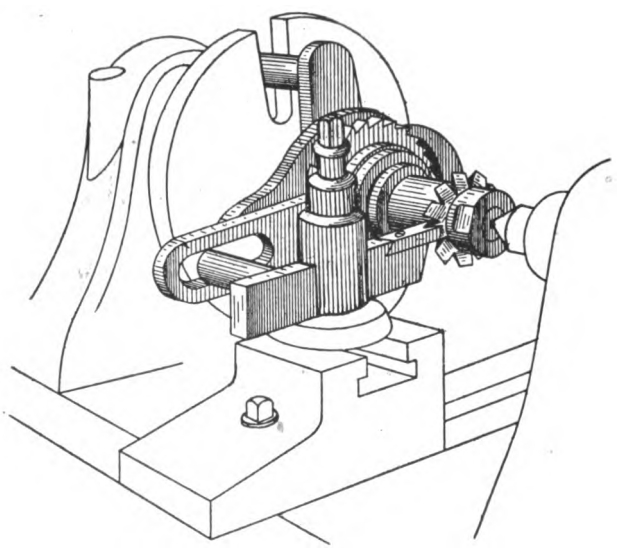


Fig. 220. Balzar Backing-Off Attachment

can be converted into a backing-off lathe for relieving or backing off the cutters. There are several commercial devices for the work: one comparatively inexpensive fixture is known as the "Balzar" backing-off attachment, Fig. 220; another arrangement consists simply of an eccentric arbor operated by a hand lever; or, a stud may be screwed into the faceplate of a lathe and the cutter placed on this stud in a position that allows the teeth to be given the necessary amount of clearance.

When backing off the teeth of cutters whose faces do not exceed one inch in width, the Balzar backing-off fixture can be used to advantage. This device is held between the centers of a lathe in

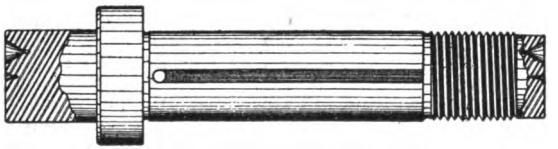


Fig. 221. Special Arbor for Backing Off

the ordinary manner, the backing off being such that the cutter can be ground without alteration of shape. The tool is so constructed that it is only necessary to place the cutter upon the arbor in the ordinary way. Place the arbor on the lathe centers as shown, start the lathe, and feed the forming tool in by the cross-feed screw in order to take the desired cut, in the same manner as in plain turning. The ratchet connected with the arbor and actuated by the pawl, contains ordinarily 36 teeth, and the stroke can be set to back off a cutter with 9, 12, 18, or 36 teeth.

Backing Off by an Eccentric Arbor. An arbor may be made having a pair of centers located to give the cutter tooth the required amount of clearance; such an arbor is shown in Fig. 221. The eccentric centers are shown at the sectional portions at the ends. The amount of eccentricity depends somewhat on the size of the cutter to be backed off, but for cutters not exceeding 4 inches in diameter, from $\frac{3}{16}$ to $\frac{1}{4}$ inch will give excellent results.

The screw at the end of the arbor should be of a fine pitch, about 12 threads per inch for arbors one inch in diameter. The object in

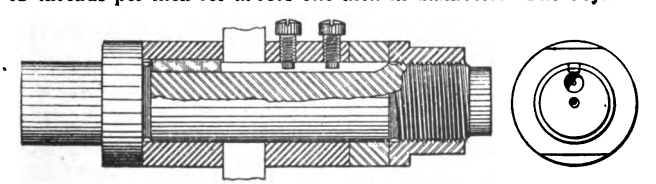


Fig. 222. Eccentric Arbor for Backing-Off Cutter

cutting a fine-pitch thread is that the cutter, being backed off, can be held more securely with the same amount of force exerted in tightening the nut; again, the depth of the thread is not so great as

for a thread of coarser pitch, and, as a consequence, the plane portion at the end of the arbor, which is made the size of the bottom of the thread, can be left large enough to get in a center hole of good size having $\frac{1}{4}$-inch eccentricity.

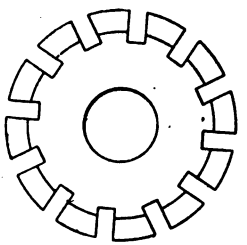


Fig. 223 Cutter Blank with Straight Grooves

The spline should be cut at least $\frac{1}{8}$ inch wide and about $\frac{1}{8}$ inch deep; the walls of the cut should be parallel in order that the screws shown in Fig. 222 as passing through the collar and entering the slot in the arbor, may have a good bearing. These screws are to keep the collar from turning when the necessary force is applied to the nut for fastening the cutter in place. The collar on the opposite side of the cutter has a spline cut the same width as that in the arbor, and it is held in position by a spline, as shown. The cutter itself cannot be held by a spline, as it is necessary to move it each time a tooth is brought into position for backing off.

The cutter blank, when machined, is given the desired shape by means of a forming tool. If there is much variation in size, the shape should be roughed out before using the forming tool. After it has been machined to the desired size and shape, the cutter should be placed between the centers of the milling machine and a number of grooves cut its entire length. The number of grooves must correspond to the number of teeth the mill is to have; the grooves cannot be cut to finish width until after the teeth are backed off, because the forming tool cuts a trifle deeper at the point of contact, making it necessary to mill a small amount from the face of the tooth after backing off. The grooves are sometimes cut with a thin milling cutter, or a metal slitting saw $\frac{1}{8}$ inch thick. When a groove of this description is cut, the cutter has the appearance shown in Fig. 223. A groove of this form makes more work for the operator than one cut as shown in Fig. 224, in which the distance across the tops of the

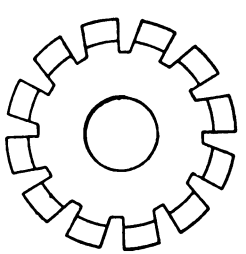


Fig. 224 Cutter Blank with Grooves Made by Angular Cutter

teeth is decreased by using an angular cutter of the shape shown in Fig. 225.

After the grooves have been made, the cutter is placed on the eccentric arbor, which is held between the centers of the lathe in the ordinary manner. A forming tool that will produce the desired shape of tooth is placed in the tool post; the top face of the tool must be set at the exact height of the center of the lathe in order to produce the proper shape. Fig. 226 shows an eccentric arbor in a lathe in position to back off the teeth in a formed mill. The arbor is operated by means of the lever, and is entirely independent of the spindle in its action, the eccentric centers being placed on the centers of the lathe, and the necessary motion given by means of the lever which strikes the carriage at the end of the stroke. In order to avoid bruising the lathe, a strip of leather is attached to the lever, as shown.

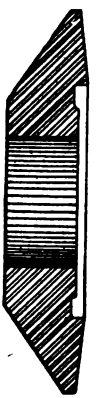


Fig. 225. Section of Angular Cutter

To set the cutter tooth in the proper location before backing off, a piece of thin sheet metal is placed on the top face of the tool, as shown in Fig. 227. The lever is

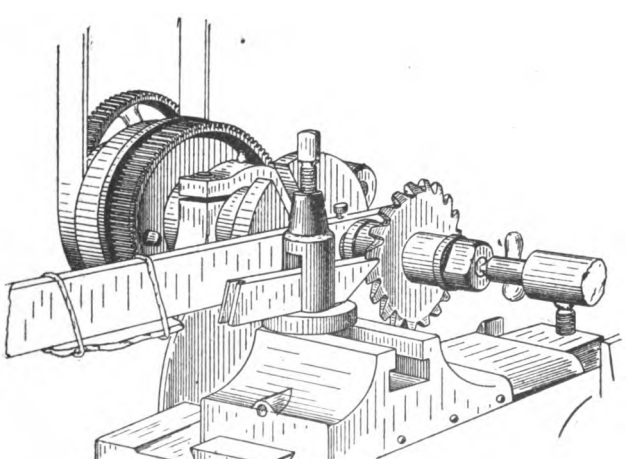


Fig. 226. Set-Up for Backing Off Cutter Teeth in a Lathe

brought down upon the carriage, the tooth of the cutter is brought down upon the sheet metal, and the nut is tightened. The tooth to be backed off is the one below that set to the thickness of the strip above the tool. The object in raising the tooth a given distance above the face is to prevent striking the tool at the end of the stroke. This operation must be repeated for the setting of each tooth before backing off. The forming tool is fed by means of the cross-feed screw; a tooth is backed off nearly the desired amount, leaving a little for a finish cut; the tool is withdrawn, the nut

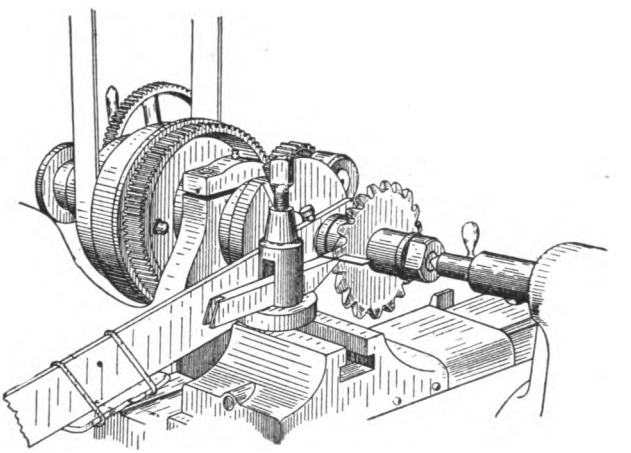


Fig. 227. Method of Locating Cutter Tooth for Backing Off

loosened, and the cutter turned on the arbor to bring the next tooth in position to be backed off, this operation being repeated until all the teeth are backed off alike. The amount of backing off must be determined by the cross-feed stop or by a graduated dial on the cross-feed screw. After the roughing cut has been taken on all the teeth, the forming tool should be sharpened by grinding or by oil-stoning, and the finish cut taken on the teeth.

Backing Off by Stud in Faceplate. Another method of backing off cutter teeth is shown in Fig. 228. A stud is screwed in the faceplate of a lathe near the outer edge, as shown. The cutter, which must be a fit on the stud, is clamped by means of the nut. The finger

A is movable in the slot in the stationary block *B*, which is so located on the faceplate as to bring the tooth to be backed off into its proper location, and to keep it from turning during the operation. The forming tool is fed in gradually until the tooth is formed. The finger is then disengaged from the space in the cutter, which is revolved by means of the set screw until the next tooth is in position. Each tooth is machined separately; that is, the forming tool is fed in the required distance for each tooth when it is in position, the cutter is turned until the next tooth is in position, and the process repeated until each tooth has been backed off. In backing off cutters in this

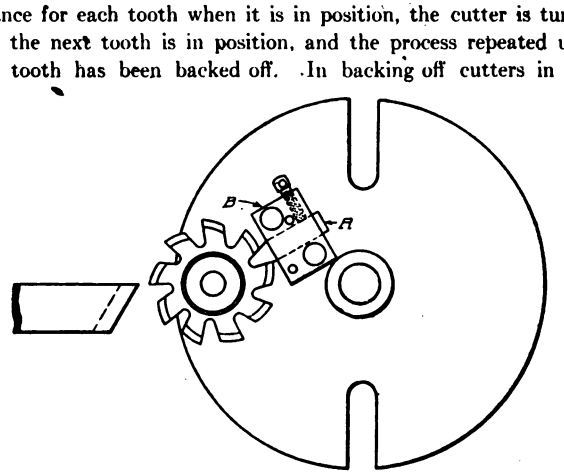


Fig. 228. Set-Up for Backing Off Cutter on Faceplate

device, it is necessary to cut the notches (the spaces between the teeth) somewhat wider than the teeth.

General Directions for Backing Off. When backing off the teeth for clearance by any of the means described, it is first necessary to form the blank, then to gash it or to cut the notches as described; then to back off the teeth. After backing off, it is necessary to mill the face of the tooth back $\frac{1}{32}$ inch or so, to cut away the "jump", as it is termed, caused by the forming tool drawing in a trifle when it first strikes the edge of the tooth.

Cutters of this description are sharpened by grinding on the face of teeth, as shown in Fig. 229.

Milling Cutters with Threaded Holes. It is often necessary to make milling cutters with threaded holes. This happens in the case

of small angular cutters, and in many styles of cutters for use on profiling (edge milling) machines.

The general instructions given for making the other forms of cutters apply to those with threaded holes, except that instead of

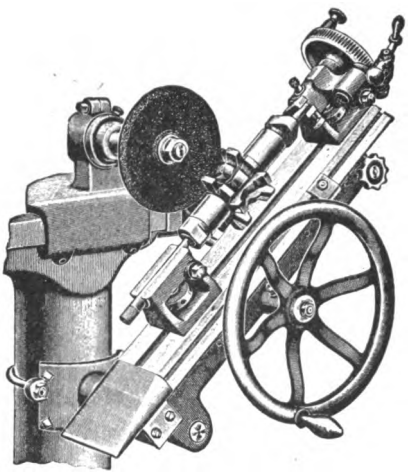


Fig. 229. Method of Grinding Formed Cutters

reaming the hole to a given size, the thread is cut with a tap of the proper size and pitch, or it is chased in the lathe. After threading, the cutter should be screwed on to a threaded arbor. Fig. 230 shows an arbor of this description. The end *A* is threaded slightly taper-

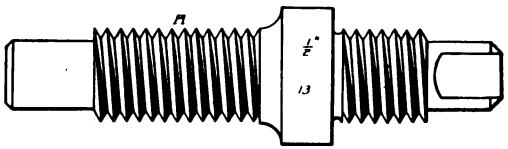


Fig 230. Typical Threaded Arbor

ing, for short cutters about .002 inch in one inch of length. On the taper end of the arbor, a thread should be cut of a size that will not allow the cutter to screw on the arbor quite the entire length; that is, the cutter should overhang the threaded portion of the arbor a

trifle, say one thread. This allows the outer end to be squared up without mutilating the threads on the arbor. The reason for using the taper end of the arbor when squaring the first end of the cutter is that the shoulder is true with the thread in the cutter. After squaring this shoulder, the cutter blank may be removed and placed on the opposite end of the arbor with the side that has been squared against the shoulder of the arbor.

This method of machining pieces of work having a threaded hole, where it is desirable that the outer surfaces be true with the hole, is applicable to all classes of work. The cutter may be machined to length and shape on the straight end of the arbor.

Fly Cutters. The simplest form of milling machine cutter is known as a fly cutter. It has only one cutting edge, but is particularly valuable when making but one or two pieces of a kind for experimental work, and when making and duplicating screw-machine and similar tools of irregular shape. As these cutters have but one cutting edge, they produce work very accurate as to shape, but they cut very slowly and do not last so long as those having more teeth. However, they are used on special work, on account of the small cost of making. It is necessary to hold the cutters in a *fly cutter arbor*, Fig. 231.

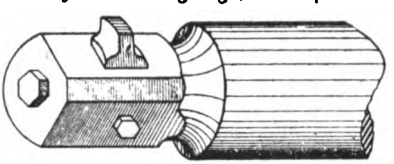


Fig. 231. Fly-Cutter Arbor

The cutter to be used in a fly cutter arbor may be filed to a templet, giving the necessary amount of clearance in order that the back edge, or "heel", may not drag. If it is desirable to make the impression in the fly cutter with a milling cutter of the regular form, the piece of square steel from which the cutter is to be made may be held in the milling machine vise, and the shape cut with the milling cutter. The desired amount of clearance may be given by holding the piece in the vise at an angle of a few degrees.

To make a fly cutter from the forming tool, the piece of steel may be held in the fly cutter arbor in such a position that the face is somewhat back of a radial line, as shown in Fig. 232. After hardening, the cutter should be set so that the cutting edge will be radial, and the clearance will be as shown in Fig. 233.

Another method of getting the clearance for the cutter is to place the top of the cutter blank as near the arbor as possible, and then to cut the desired shape. If the cutter is set in the arbor so that it

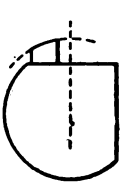


Fig. 232 First Step in Making Fly Cutter

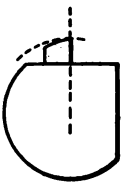


Fig. 233. Fly-Cutter Set Radial with Clearance Provided

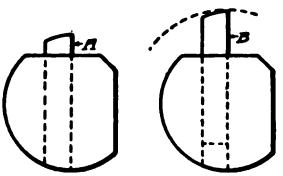


Fig. 234. Simple Method of Getting Clearance on Fly Cutter

projects from the surface, it will have the necessary clearance, as shown in Fig. 234. *A* represents the position of the blank while being cut, and *B* the cutter in position for cutting; as the dotted line shows the circle through which the cutting edge travels, the amount of clearance is apparent.

End Mills. This form of milling machine cutter, Fig. 235, is familiarly known as a *shank mill*, on account of the shank, which in small milling cutters fits into a collet. This collet in turn fits the hole in the spindle of the milling machine; the collet is used to save stock in making the cutters, as otherwise it would be necessary to use steel large enough to make a shank the size of the hole in the spindle of the milling machine.

The cutter shown in the figure is what is termed a *left-hand* mill; if the teeth run in the opposite direction, it is called a *right-hand* mill

In making a shank, or end mill, of the form shown, stock should be selected enough larger than the cutting end to allow of turning

Fig. 235 Straight Flute Left-Hand End Mill
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

off the decarbonized surface of the steel. After the ends have been faced to length, and the roughing chip turned, the cutting end can be run in the steady rest of the lathe, and the center cut away, or

recessed, as shown at the end of the mill. The blank should be re-centered and countersunk, to furnish a center to use in turning the mill to size and shape. The object in cutting the center out as shown is to furnish a cavity for the angular cutter used in cutting the teeth on the end of the mill. Without the recess, it would be impossible to grind satisfactorily.

After re-centering the recessed end, the opposite end should be turned to size and milled to thickness, which should be a trifle $\frac{1}{32}$ inch—less than the width of the center key slot in the collet. The taper shank should be turned enough larger than finish size to allow for grinding after the milling cutter is hardened; the cutter end should be turned .010 inch larger than the required diameter; the portion just back of the cutters should be turned $\frac{1}{32}$ inch smaller than

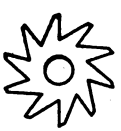


Fig. 236. Cutter with Weak Teeth

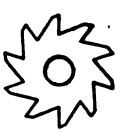


Fig. 237. Cutter with Well-Formed Teeth

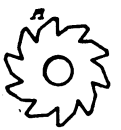


Fig. 238. Cutter with Especially Strong Teeth

Fig. 239. Method of Cutting Strong Teeth

the large end of the shank, or to dimensions, if any are given on the drawings.

In order to insure teeth strong enough to resist the strain of cutting, an angular mill should be selected that will give the required shape. In Fig. 236 is shown a form of cutter tooth too weak for actual service, the result of using an angular cutter with a cutting face forming an angle that is too acute with the side. Fig. 237 illustrates a cutter whose teeth are strong, yet deep enough to be practical; these teeth were cut with an angular mill of smaller angle. Fig. 238 represents a cutter whose teeth were cut with the same cutter used for Fig. 236. The teeth were cut to the required depth first, but this of course left them too thick at the cutting edges *A*, Fig. 239, and the index head was turned sufficiently to cut the teeth as shown at *A*, Fig. 238.

After the teeth around the circumference of the mill have been cut, the mill should be placed in the collet, and the collet put in the spindle hole in the spiral head to cut the teeth on the end. When

the teeth on the end of the mill are being cut, the spiral head is turned until the cutter is in a horizontal position. The angular cutter used should not have a very acute angle, or the teeth will be weak.

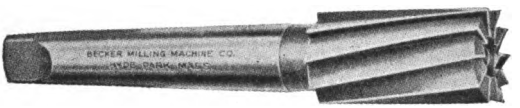


Fig. 240. Spiral End Mill
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

An 80-degree angular milling cutter will be satisfactory for most work.

Spiral End Mills. It is sometimes advisable to cut the teeth of end mills spirally, as shown in Fig. 240. As there is no support at the outer end of this form of mill, it will be necessary to cut the teeth of a spiral that will have a tendency to force the mill into the collet rather than to draw it out. Fig. 240 represents a left-hand end mill cut with a right-hand spiral.

End Mills with Center Cut. This form of end mill is useful when it is necessary to cut into the work with the end of the mill, and then move along, as in the case of dies, cams, and grooves. The teeth, being sharp on the outside, cut a path from the point of entrance, and, being coarse, allow a heavy cut, especially in cast iron. Fig. 241 shows two views of an end mill with center cut.

After the teeth on the end have been cut with an angular cutter, a thin, straight-faced cutter of small diameter should be run through, close to the face of the cutter tooth, making a cut as shown at *A;* this cut should be of sufficient depth to permit backing-off the inner

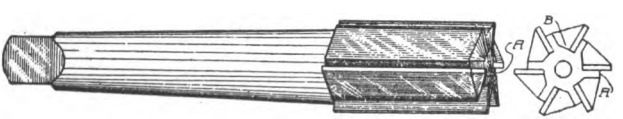


Fig. 241. Form of End Mill with Center Cut

edge of the tool, as shown at *B*. This clearance allows the mill to cut away the slight projection left in the center of the mill when it is fed into a piece of work, Fig. 242.

T-Slot Cutters. In cutting T-slots in various parts of machines, such as milling machine carriages, etc., it is necessary to use a form of shank mill known as a T-slot cutter. Fig. 243 shows the ordinary form of T-slot, while Fig. 244 shows the cutter. A portion of the stock below the teeth is cut away, as shown at AA in the sectional view, Fig. 245. This is necessary in order to back off the teeth on the sides of the cutter for clearance, and to do away so far as possible with unnecessary friction when the cutter is working.

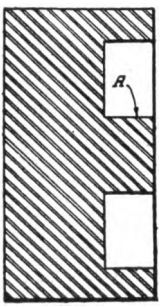


Fig. 242. Section Showing Projection Left by End Mill

T-slot cutters are usually made $\frac{1}{32}$ inch larger in diameter than the size designated on the cutting portion, to allow for sharpening; that is, a mill intended for cutting a slot $\frac{1}{2}$ inch wide is made $\frac{1}{2}+\frac{1}{32}$ or $\frac{17}{32}$ inch in diameter, unless intended for cutting a slot to given dimensions.

It is advisable to harden mills of this description the entire length of the neck, especially if that is of small diameter; for otherwise they will be very likely to spring when in use. After hardening, the neck should be drawn to a blue color, while the cutting part should be drawn to a straw color.

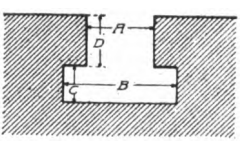


Fig. 243. Section Showing Typical T-Slot

When grinding end mills, the shank in all cases should be ground first to fit the collet or holder, allowing it to enter far enough to key out readily, but yet not enough to allow the shoulder above the tenon to strike the shoulder in the collet.

Fig. 244. T-Slot Cutter
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

After grinding the teeth for clearance on the diameter, the teeth on the end should be ground. Most universal and cutter

grinders are provided with a fixture for holding the mill by the shank while grinding these teeth, Fig. 246.

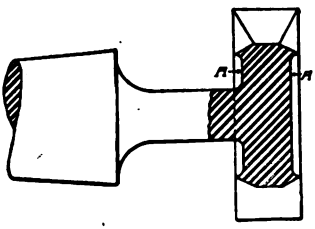


Fig. 245. Section of T-Slot Cutter

Face Milling Cutters. This form of cutter is used in milling surfaces too large to be cut with the ordinary form of milling cutter held on an arbor passing over the work. As the full diameter of the face of the cutter can be used, it can have less than one-half the size that would be necessary for a side milling cutter. A side milling cutter must be double the diameter of the surface to be cut, plus the diameter of the collar on the arbor. For instance, if a surface as *A*, Fig. 247, were to be milled, it would be necessary to use a cutter somewhat larger in diameter than twice the height of the surface plus the diameter of collar *B;* whereas, if a face milling cutter of the form shown in Fig. 248 were used, the diameter need not be much greater than the height of the face of the piece of work being milled.

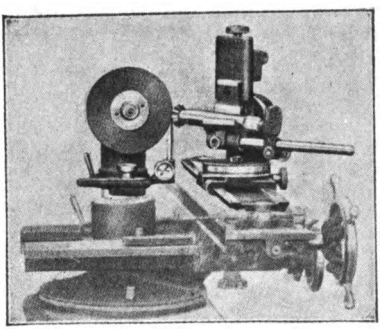


Fig. 246. Grinding Attachment for Shank Cutters
Courtesy of Norton Grinding Company, Worcester, Massachusetts

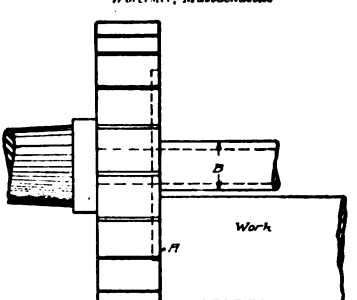


Fig. 247. Side Milling Cutter on End Work

Generally speaking, cutters of this description are necessarily of a diameter that makes it advisable to use inserted teeth. The body may be made of cast iron, having a taper hole and key-

TABLE VIII

Dimensions of Face Milling Cutters

Diameter of Cutter (in.)	Width of Face (in.)	Taper of Hole (Brown & Sharpe Taper) (No.)
5½	2	10
6½	2	12
7½	2	12
8½	2½	12
9½	2½	12

way, and held in place on the arbor by a screw.

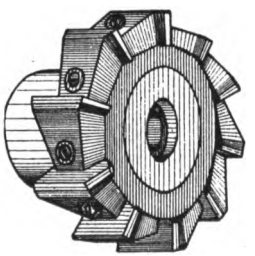


Fig. 248. Face Milling Cutter

The teeth should be made of tool steel and hardened, or of high-speed steel, if the cutter is to be subjected to rough usage. In either case, they can be fitted to the slots by grinding on a surface grinder, and held in place by taper bushings and screws, as explained under "Milling Cutters with Inserted Teeth". The construction of the body can be readily understood from the sectional view given in Fig. 249. The letters *A*, *B*, and *C* represent diameter of cutter, width of face, and number of taper of the hole, respectively, while *D* represents the keyway.

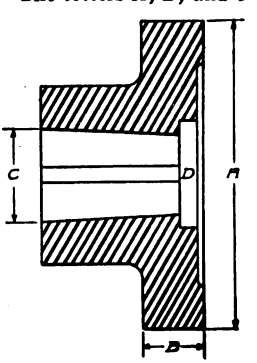


Fig. 249. Body of Face Mill

Table VIII gives the dimensions of face milling cutters of different diameters.

After the taper hole has been bored and reamed, the body of the cutter should be placed on a taper mandrel fitting the hole, and the ends and circumference finished to size. It is then put in the vise on the shaper or planer at the proper angle, and the spline slot cut to an equal depth at each end of the taper hole. The burrs having been removed, the cutter should be placed between the centers on the milling machine, and the slots cut for the teeth.

When the teeth are firmly secured in their proper places, they should be ground for clearance, in accordance with the general instructions already given for grinding other forms of milling cutters.

Arbors for Face Milling Cutters. In Fig. 250 is shown an arbor to be used in connection with face milling cutters. The shank *A* fits the hole in the spindle of the milling machine. *B* is the body which fits the taper hole in the cutter; this portion of the arbor has a spline which fits a spline slot in the cutter. The screw *C* enters the body of the arbor, and holds the cutter on the arbor. *D* is a nut used to force the cutter off the arbor when it is necessary.

Stock used in making such an arbor should be strong and stiff, and on this account tool-steel is generally used. With the ends squared and the circumference roughed out, one end should be run in the steady rest, and the screw hole in the end drilled and tapped;

Fig. 250 Arbor for Face Milling Cutter

after which the arbor should be countersunk at the end to furnish a center for use in turning and finishing. If necessary to harden the end of the tenon, that should be done before finish-turning the arbor, to prevent springing when heating. When the taper has been turned to fit the hole in the milling machine spindle, and, on the opposite end, to fit the cutter, the thread can be cut for the nut *D*, after which the arbor is cut for the spline as already explained.

The result will be more satisfactory if the two tapers are left a trifle large until after making the spline cut, and are then ground to fit. Although the spline is intended to fit snugly in the slot in the arbor, the fit should not require pressure enough to endanger the trueness of the arbor when it is pressed to position.

MILLING MACHINE FIXTURES

When producing work by milling operations, it is necessary to use good cutters; it is equally necessary to employ suitable means of holding the work. It is a waste of money to make costly cutters and

to purchase a strong, heavy machine, and then to use a weak, poorly designed holding device. When unsuitable holding fixtures are used, accurate work cannot be produced unless extremely slow feeds are employed, and even then it is many times impossible. In fact, the designing of fixtures to hold work in the milling machine calls for as great a display of ingenuity as the designing of any class of tools used in the shop.

Essential Features. Years ago almost all pieces produced by the milling machine were purposely left large in order that they might be brought to exact size by filing. Today most pieces are milled to finish size, thus doing away with the costly operation of filing. But in order to produce work of the desired accuracy, cutters must be used that are of the right shape; machines must be provided that are strong, rigid, and easily operated; holdfasts must be employed which will hold the work and insure its being presented to the cutter in such a manner that all pieces will be alike, so that perfect interchangeability of parts will be secured. This is impossible with light fixtures, as they will spring, and not only will the sizes vary, but the surface of the work will be covered with chatter marks.

The fixture must be rigid and strong, and the holding devices must be of a design that allows rapid handling of the work. All bearing and locating surfaces and points must be accessible, for the sake of ease in cleaning, as dirt, or a collection of chips, at times the presence of even one chip, might change the location of the piece to an extent that would prove fatal to the work.

Most fixtures of this kind are made from cast iron, and as this is a cheap metal that is easily shaped, it is possible to supply a sufficient amount to insure necessary rigidity. For fixtures that are to be used over and over, it is advisable, generally speaking, to supply seating and binding surfaces of hardened steel.

Simple Angle Iron Holder. When designing fixtures, plan to have the strain incident to binding and cutting the work come, if possible, against the strongest part. Fig. 251 shows several holding devices. *A* is made in the form of an angle iron. The binding and the cutter strain both come against the rigid part. If the fixture were reversed, the cutter strain would come against the strap, and it would be found impossible to produce work to gage if heavy cuts or moderately coarse feeds were employed.

Milling Machine Vises. *Usual Type.* In the same figure, at *B*, is shown a portion of a milling machine vise, the work being held between steel jaws. If the work were of a character that made it possible to use jaws extending but little above the top of the vise, it

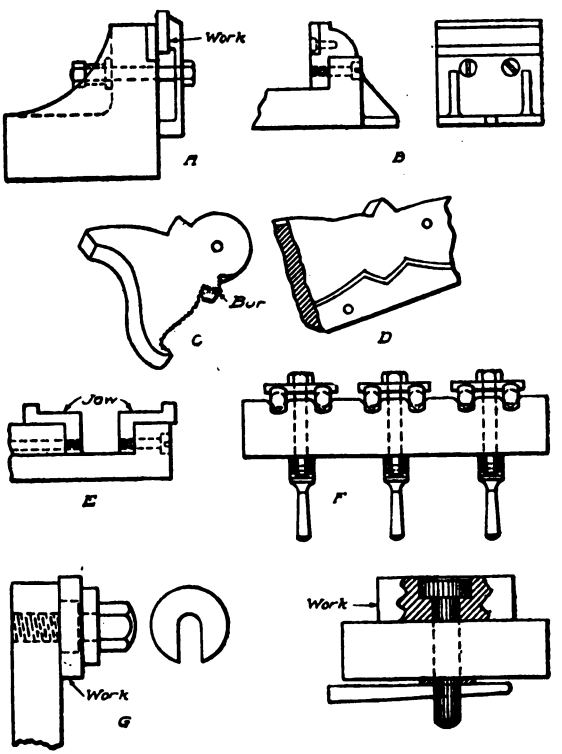


Fig. 251. Forms of Milling Machine Holdfasts

would not be necessary to use heavy ones; but in the illustration, the jaws extend considerably above the top of the vise, and even heavy ones would spring, or would draw away from the vise at the bottom, thus throwing the work out of true. To prevent this, they are made of the form shown, and bear on the top of the vise.

Taking Care of the Burr. When pieces are milled, a burr is thrown out, as shown at *C*. At times, this burr will bear against the bearing surfaces of the fixtures, and throw the work out of true; and it will also be pressed into the work, thus mutilating and spoiling it. Frequently these burrs are removed by filing or grinding. At times this seems an unwarrantable expense, as subsequent operations would cut them away at no expense; under such conditions, it is possible to cut into the bearing surface and remove enough stock to provide a place for the burr, as shown at *D*.

Use of Extra Jaws. When it seems advisable to hold work in the vise, and the opening is not sufficient to take in the piece, the jaws may be made as shown at *E*.

Milling Vise Operated by Compressed Air. A milling machine vise that is very satisfactory for many classes of work is opened and closed by compressed air, which is carried to the various machines in pipes. When compressed air is so used, it is often further employed to clean the jaws. This operation requires a piece of flexible hose having a suitable valve which can be opened so that the chips and dirt can be blown from the jaws. By this method it is easy to get rid of small chips in places hard to reach with a brush. In fact, compressed air is many times used in cleaning vise jaws where the vise is opened and closed by means of a screw or cam, the air being automatically turned on as the jaws open.

Cams. When a cam will fasten the work to the fixture strongly enough, it proves a rapid method, and one that is often employed. At *F*, Fig. 251, is shown a fixture for holding bolts the heads of which are to be straddle-milled. One cam binds two bolts, and as three cams are provided, six bolts may be milled at a time. The fixture is so designed that the cam handles are at the front of the fixture rather than back of the cutters, as in this position the operator's hands would be in danger. The cutter pressure is against the solid part of the fixture, thus insuring rigidity.

Screws. At times cams do not prove satisfactory, and it is found necessary to use a screw. Screws are slow of operation, as it takes a long time to turn them back and forth sufficiently to bind or free the work. To facilitate matters, a slotted washer *G*, Fig. 251, is sometimes provided, and a screw which passes through a hole in the work is used. By this means it is only necessary to give the

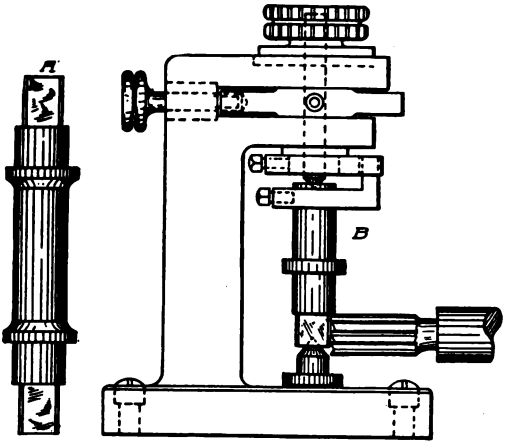


Fig. 252. Method of Holding Work for Milling Ends Square with End Mill

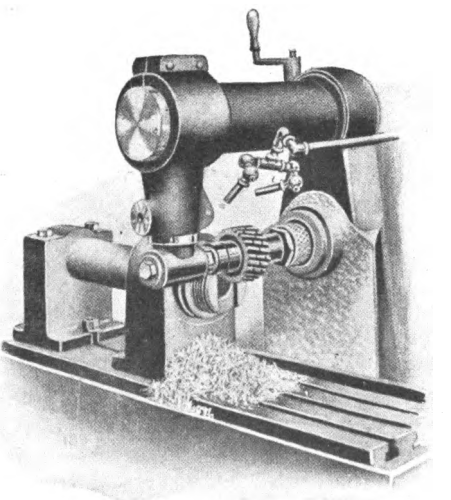


Fig. 253. Set-Up for Milling Slot across End of Lathe Spindle

screw a part of a turn in order to bind or remove the washer thus giving a very quick action.

Wedge-Shaped Keys. When it is necessary to place the binding device on the under side of a fixture or in some inaccessible place, a wedge-shaped key, as shown at *H*, Fig. 251, proves satisfactory. It holds the work solidly on to the seating surface, and is quickly and easily operated.

Special Holders. In Fig. 252, at *A*, is shown a piece of work whose ends are milled square. As the sides are machined on a slight

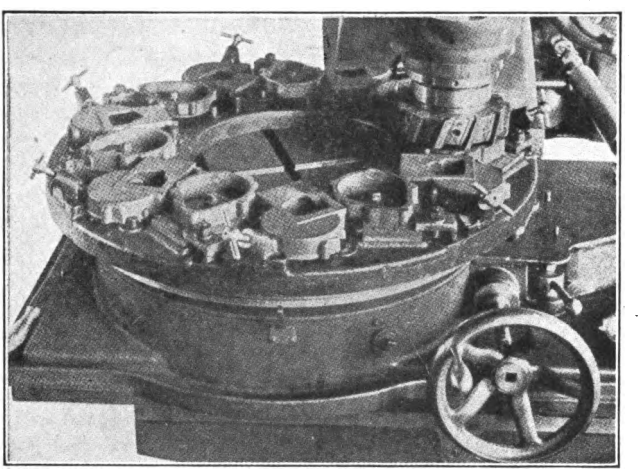


Fig. 254. Set-Up on Vertical Milling Machine for Milling Automobile Starter Covers
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

taper to the axis of the piece, it was necessary to hold the work as shown at *B*, and use an end milling cutter.

In making fixtures of the kind under consideration, the designer should bear in mind that the simplest form which will insure desired results at the minimum cost is the best. Complicated fixtures should always be avoided, if a simple one will answer.

Fig. 253 shows a method of holding a spindle and milling a slot across the end. The work is held in a fixture made in two parts, and the cut is taken by feeding the knee vertically by means of the auto-

matic vertical feed. With a fixture of this description, the ends of long pieces can be milled as shown.

Holders for Vertical Milling Machines. Fig. 254 shows a fixture for holding work in a vertical milling machine, by the use of which the process of milling is continuous. After a piece is milled, it is removed and another put in its place while other pieces are being milled. For many jobs of flat milling this method is to be recommended as there is no lost time.

The problem in the up-to-date shop is to turn out all the work possible in a day with the minimum expenditure for labor. By this method of milling, the machine is cutting constantly, and the entire time of the operator is employed in taking out, putting in, and gaging the work. This is not the case where a man has several milling machines of the ordinary type to tend; for then the time of the operator is wasted when he walks from one machine to another, and the time of the machine is wasted when it lies idle and unproductive while the fixtures are being loaded and unloaded.

DRILL JIGS

A drill jig is a device for holding work so that one or more holes may be accurately drilled; the locations of the holes may be governed by hardened bushings (guides) through which the drills run

The design of a jig depends entirely on the shape of the piece and the nature of the work to be done, but it must be such that work may be placed in them and taken out as quickly as possible. The fastening device should allow rapid manipulation, yet be capable of holding the work without danger of a change of location.

The construction of drill jigs calls for as great accuracy as any branch of the tool-maker's business, but no undue accuracy should be indulged in. If the location of a hole is near enough when within a limit of variation of $\frac{1}{16}$ inch, it is a waste of time to attempt to get it within .0005 inch; yet if the work is of such character that it is necessary for the holes to be within a limit of variation of .0001 inch or even closer, every effort should be made to locate the drill bushings as accurately as possible.

Important Construction Features. *Finish.* While the design of the jig and the character of the work to be drilled must necessarily determine the method of construction, a few general directions may

not be amiss. The amount of finish given the exposed surfaces of a jig must be determined by the custom or requirements of the individual shop. In many shops it is not considered necessary or advisable to finish the surfaces any more than to allow of their being wiped without the waste sticking to the jig.

Under other conditions the surfaces are machined as smooth as possible, and the surface finished by placing a piece of $\frac{1}{2}$- or $\frac{3}{4}$-inch wood dowel in the drill-press chuck, so that the dowel projects $\frac{3}{4}$ inch or so from the chuck. The surface of the metal is covered with a thin coating of oil and fine emery, and the dowel, revolving at high speed, is brought down upon the surface, allowed to run for a few seconds, raised, and again lowered so that it cuts part way into the first circle. This is repeated until the whole surface is covered with the part circles. The effect is pleasing and the surface is not easily marked by light scratches that would show plainly on a highly finished piece of steel. It is an economical method of producing a fairly good finish.

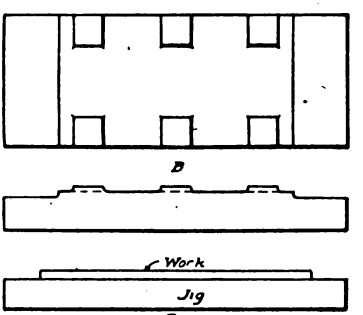


Fig 255. Seating Surfaces for Drill Jigs

Ease of Cleaning Bearing Surfaces. A jig should be constructed so that it can be easily cleaned. Chips or dirt between the piece of work and the seating surface, or between the work and the stops, or locating points, throw the work out of true, and, as a result, the holes will be at a wrong angle to the working surface, or they will be improperly located. Either condition would make the pieces unfit for use on most work; consequently, bearing surfaces should be cut away, wherever possible, leaving several small seating surfaces, rather than one large one. In *A*, Fig. 255, is shown a piece of work resting on its entire seating surface, while *B* shows a surface cut away to leave six bearing points. If the seating surface is to be cut away, the raised portions should be so located that the article cannot be sprung by the action of the cutting tools or from any pressure that may be applied by any fastening device; otherwise the work will be

thrown out of true as badly as though chips were lodged between the work and the seating.

It is advisable, whenever possible, to divide a long locating bearing into several short surfaces, and thus to decrease the chance of holes being inaccurately located. When making jigs for pieces that are likely to have burrs at any given point, it is well to cut a depression in the seating or locating surfaces for the burr, thus preventing the work being incorrectly located.

Seating surfaces should be made smooth so that chips and dirt will not stick to them; but they should not be polished or finished, as this would involve unnecessary cost and might throw the surface out of true.

Avoidance of Clumsy Design. A jig must be handled by the workman, and a clumsy jig is difficult to manage. Sharp corners should be avoided wherever possible, and all handles or similar devices should fit the hand; if they do not, the amount of work done will not be the maximum, as the operator cannot do so much work with a jig which tires the hand and wrist.

As already stated, the accuracy with which a jig should be constructed depends entirely on the nature of the work to be done; yet it should be borne in mind that any inaccuracy must of necessity be duplicated in the work.

Simple Slab Jig. A few designs of jigs will now be considered, to show the general requirements and the methods of construction.

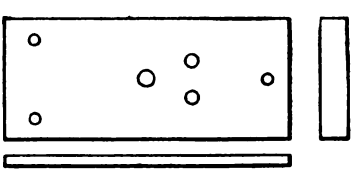


Fig. 256. Slab Jig

The slab jig, Fig. 256, is the simplest form in use; it consists of a piece of flat stock of suitable thickness and of the same general outline as the piece to be drilled. The work may be clamped to the jig by means of U-clamps, or parallel-jaw clamps. If the jig is made of machine steel, the walls of the holes should be casehardened by heating the jig red hot and sprinkling powdered cyanide of potassium around the hole, reheating it in the fire, and plunging it into water; it should be worked back and forth in the bath so that the water will circulate through the holes.

Slab Jig with Bushing Holes. While the simple slab jig answers very well where but a few pieces are to be drilled, it is not suitable for permanent equipment on account of the wear of the holes. To overcome this, the holes may be made sufficiently large to receive hardened bushings having holes the size of the drill to be used. Fig. 257 shows this construction.

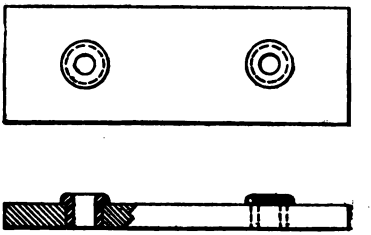


Fig. 257 Jig Provided with Bushings

Stops and Holders for Work. When holes are to be drilled at certain distances from one or more edges, it is necessary to have stops against which the work may rest. These stops may be pins, a shoulder, or a rib.

If the outline of the work has been finished by any process that insures uniform lengths and widths, such as milling, punching, or profiling, the locating points may be placed on all sides of the piece in which pins are used as stops or locating points, as shown in Fig. 258. It is necessary to flatten the pins on the sides that come in contact with the work, to prevent rapid wear.

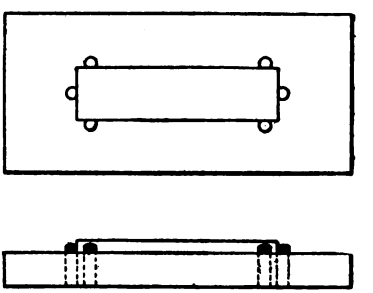


Fig. 258. Locating Pins on Jigs

When a jig is to be used constantly, it is advisable to have a shoulder or a rib rather than pins, for the work to rest against, as the former will not wear so rapidly as pins. Fig. 259 shows the same form of jig as Fig. 258, except that ribs are substituted for pins.

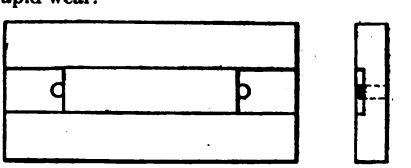


Fig. 259. Locating Ribs on Jigs

When there is no surety that the dimensions of the different

pieces are exactly alike, it is advisable to locate the pieces in the jig from certain portions. The work must be forced against the locating points by means of a screw, cam, or wedge. With a screw, the work may be forced to position and held there, even when the dimensions of the piece vary considerably. The cam is operated much more quickly than the screw, and holds the work firmly when the size of the pieces varies but little. For certain purposes, the wedge is an admirable holding device, but it is not generally used. Fig. 260 shows a jig in which the work is located from one side and end, the work being forced against the stops by means of a screw; Fig. 261 represents the same jig having a cam instead of a screw

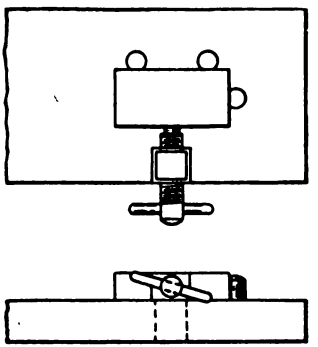


Fig 260 Jig with Pin and Screw

Locating Holes for Bushings. *Approximate Methods.* When making any of these styles of jigs, the holes to contain the bushing may be located by several methods.

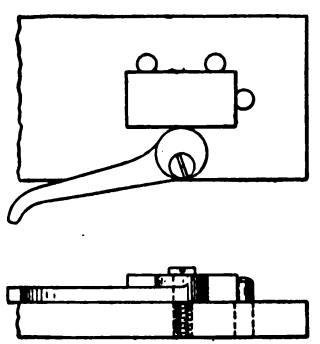


Fig 261 Jig with Cam and Pins

First Method. If extremely accurate work is not necessary, a templet may be made, or a model piece used having the holes properly located, this piece is placed in the jig and, by means of drills, the holes are transferred to the jig If the bushings are to be used, the holes may be enlarged by a counterbore having a pilot which fits the drilled hole, and a body of the desired size of the bushing While this method is cheap, and good enough for certain classes of work, it is not advisable to use it for a really accurate job.

Second Method. Another inexpensive method which insures fair results is to drill the holes as described above, and then to run a drill or reamer, a trifle larger than the holes in the templet, through the holes in the jig. Then the templet is placed in position, and, by means of a counterbore having a pilot which fits the hole in the templet, the jig is counterbored to the templet, Fig. 262. Better results will be obtained if the ends of the teeth of the counterbore are made of the shape shown in Fig. 263, especially if the drilled hole has run from its proper location.

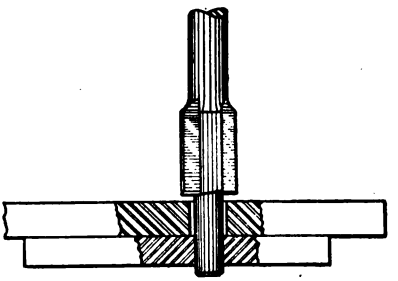


Fig. 262. Counterboring the Jig

At times, it is advisable to use a hollow counterbore, Fig. 264. A pin having one end a pressing fit in the hole in the model, and the opposite end a nice running fit in the hole in the counterbore, is pressed into the model. The hollow counterbore, being guided by this pin, cuts the bushing hole to size. The results obtained by this method are about equal to those obtained by the previous one.

Third Method. A third method is used when the bushing holes must be located by measurement, or when there is no templet or model piece. By means of a surface gage, having the point of the needle set at the proper height from a scale attached to an angle iron, Fig. 265, a dimension line is scratched on the surface which has been colored with blue vitriol. The needle is first set to the height of the

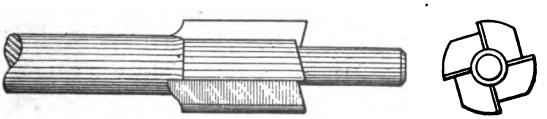


Fig. 263. Special Counterbore for Jig

locating rib. The scale attached to the angle iron is adjusted so that the needle is at the exact height of one of the inch lines, if possible; if not, at one of the half-inch or quarter-inch lines. The needle can

then be raised to locate the center of the first hole, and a line scratched while the jig is on edge. The centers of the other holes are now laid off on this plane, after which the jig is turned one-quarter of the way around to locate the hole from the other measurements; where the lines intersect, the surface of the jig should be prickpunched. For this work, the center punch made for centering work to be turned in the lathe, must not be used, but rather the prickpunch, which should be much lighter than the ordinary center punch, Fig. 266. In order that the point may be perfectly round, the point of the prickpunch should be ground in some form of grinder, in which it can be held and revolved. If this is not done, it will be impossible to get the point of the center indicator to run true when attempting to true the jig on the faceplate of the lathe.

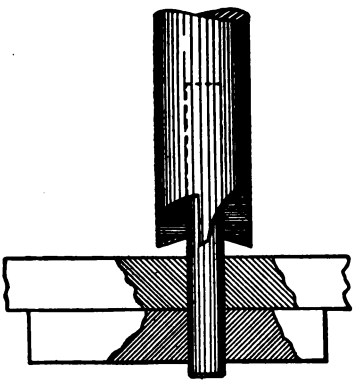


Fig. 264. Counterboring Jig with Hollow Counterbore Pin Is Pressed Solid into Model

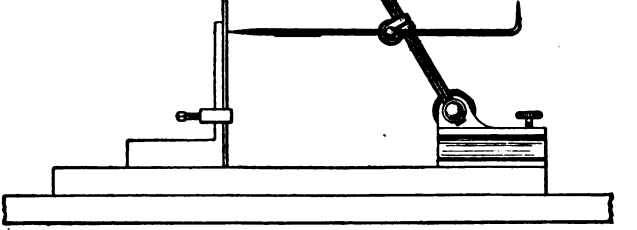


Fig. 265. Locating Holes with Templet

While the method just described might be properly classed as an approximate measurement, an experienced workman can locate the bushings within a small limit of variation. More accurate work

will result if the height gage is used in laying off the dimension lines. The bottom surface of the extension is set to the height of the locating rib, as shown in Fig. 267; then, by means of the vernier, it

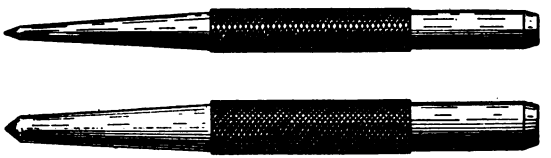


Fig. 266. Typical Prickpunch and Center Punch

can be raised to the exact height of the dimension desired, and the line scribed by means of the point of the extension. This method, although it insures greater accuracy in laying off dimension lines,

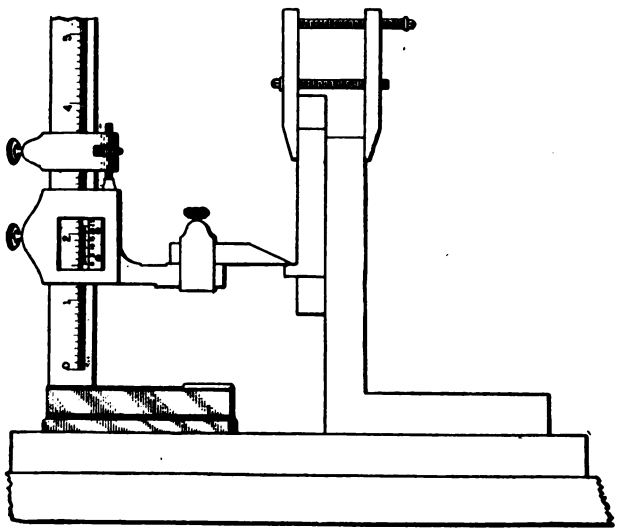


Fig. 267. Use of Vernier Height Gage for Accurate Location of Jig

and is sufficiently exact for most work, is open to the objection that the tool-maker may change the location of centers somewhat when prickpunching.

Exact Method. When precise measurements are desired, many tool-makers determine the location of bushing holes by means of hardened discs or buttons. A very common size, Fig. 268, is ½ inch in diameter, $\frac{3}{16}$ inch thick, and has a ¼-inch hole. While it is not essential that the diameter be any particular size, it must be some fraction divisible by two without a remainder, as one-half the size of the disc is considered in all computations. If the disc is .500 inch in diameter, .250 inch is the decimal to be considered; but if the disc were $\frac{9}{16}$ (.5625) inch in diameter, it would be necessary to consider the decimal .28125 in all computations. In locating the disc, most of the measurements are made with the vernier caliper, and as the tool is not graduated to read closer than .001 inch, it would be impossible to take into account the fractions of a thousandth of an inch; consequently, discs .500 inch in diameter are generally used. The locations of the different holes are laid off by means of the surface gage, the needle being set to the scale fastened to an angle iron, as already described. The holes are drilled and tapped for screws somewhat smaller than the holes in the discs, and the discs are attached to the jig by means of screws. As the screws do not fill

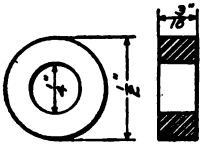


Fig. 268. Hardened Discs or Buttons

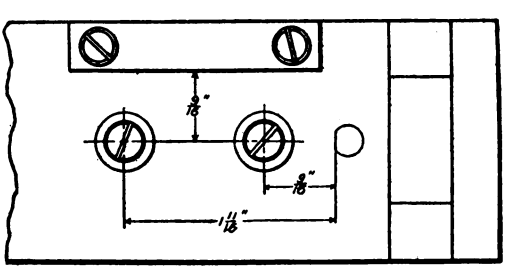


Fig. 269. Jigs with Discs Located from Stops

the holes in the discs, they may be moved until properly located. Fig. 269 shows a jig having the discs located in relation to the stops.

After properly locating a disc at each point where a bushing is desired, the jig is fastened to the faceplate of the lathe. The jig

must be so located on the faceplate that one of the discs will run *perfectly* true. This can be determined by a test indicator operating on the outside of a button, as shown in Fig. 270. After the disc has been so located, it can be removed and the hole bored to the required size. The jig can now be moved to bring another disc to the proper location, after which it is removed and the hole bored; this operation is repeated until all the bushing holes are bored.

Boring Bushing Holes on Milling Machine. In order accurately to locate and machine drill jig bushing holes on a unviersal

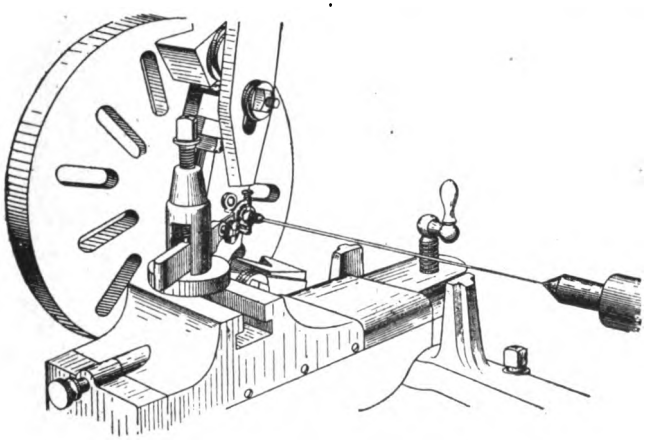


Fig. 270. Test Indicator Truing

milling machine, it is necessary to use a machine provided with a corrected screw and index dial for each of the graduated movements. With such a machine and proper tools, it is possible for the skilful workman to produce a drill jig that is correct within reasonably narrow limits. If many jigs are made and corrected screws are furnished, it is not advisable to use the machine for heavy milling. Many shops provided with such a machine do not use it for anything but jig work, and laying out models and similar pieces.

The skilful workman always looks the drawing of the jig over carefully, and selects a suitable working point from which to start. This working point should be one from which it will be possible to

move in the directions necessary in locating other working points, so that no backlash will occur in the adjusting screws. In other words, we must commence at one end and move constantly ahead.

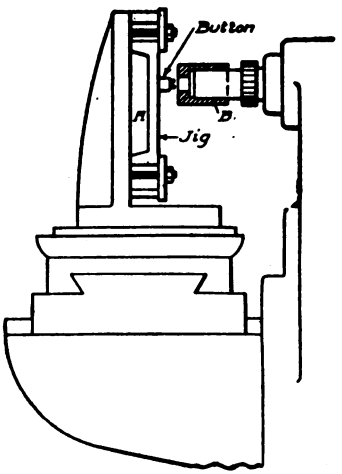


Fig. 271 Drill Jig Fastened to Angle Iron for Drilling

It may be necessary to raise and lower the knee of the machine to obtain vertical adjustments, but we should, when lowering, rather run the knee below the desired point than raise it up to it. In this way we avoid error.

Angle Iron and Indicator. If the jig can be fastened to an angle iron, as shown in Fig. 271, the face of the angle iron against which the work is clamped should be set exactly parallel to the travel of the table of the machine. A *Bath indicator*, or an indicator of the design shown in Fig. 272, may be clamped to an arbor in the spindle of the machine, or one may be held in a chuck screwed on the nose of the spindle, or in a chuck with a shank, fitting the hole in the spindle, Fig. 273. By running the table of the machine

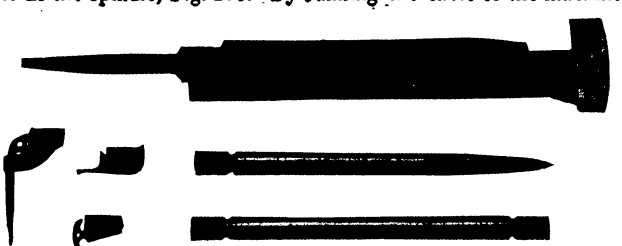


Fig. 272. Indicator for Locating Bushing Holes

back and forth with the contact point of the indicator against the face of the angle iron, and moving the iron until there is no change in position of the indicator needle, the angle iron may be correctly located.

Sleeve and Stud. A button is attached to the jig at exactly the location of the first bushing hole. The jig is fastened to the angle iron, and the proper adjustments made so that the sleeve *B*, Fig. 271, will slide over the button, making sure that the table of the machine

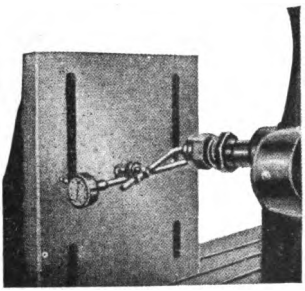


Fig. 273. Indicator with Shank Fitting Hole in Spindle for Locating Bushing Holes

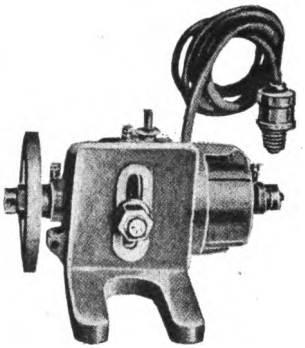


Fig. 274. Electric Grinder for Grinding Stud to Size

is moving in the direction necessary to get the other adjustments. In order to insure accuracy, it is necessary to use a sleeve having a hole which is a nice sliding fit over the button. In order that the sleeve may be exactly true, it is necessary to make the outer end of the stud somewhat large, then turn it after it is placed in the collet, the cutting tool being held in the milling machine vise. The stud revolving with the spindle may be turned by bringing it in contact with the cutting tool; the tool feed may be obtained by moving the saddle. As the modern milling machine is provided with automatic

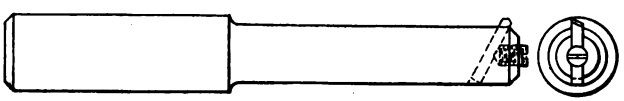


Fig. 275. Boring Tool for Drill Jigs

saddle feed, a very smooth cut will be obtained. Excellent results follow if an electrically driven grinder, Fig. 274, is fastened to the table of the machine, and the stud ground to size. It is obvious that the sleeve must be a nice fit on the stud.

Drilling and Boring Holes. When the jig has been properly located, the stud is removed from the collet, the button taken from the jig, a drill placed in the collet, and a hole drilled through the jig. A boring tool should now be placed in the collet, and the bushing hole bored to size. Various forms of boring tools are used for work of this kind. A very satisfactory form is shown in Fig. 275, the cutter being securely held by the set screw shown. When using this form of boring tool, the cutter may be moved out any desired amount, the distance being measured by the micrometer.

After boring the first hole, the table may be moved to bring the next location into position for drilling and boring. Suppose, for example, it is necessary to drill and bore bushing holes in the piece shown in Fig. 276. A button is fastened to the surface at *A;* after the location has been determined as previously described, the button is removed, and the hole drilled and bored to desired size; the carriage is then moved 1.1875 inches, and the hole is drilled and bored. The knee is then raised 1.0625 inches; the hole *B* is drilled and bored; the carriage is again moved 1.250 inches, and the hole *C* drilled and bored. The jig is then removed from the angle iron, the bushings made, hardened, ground, and forced to place.

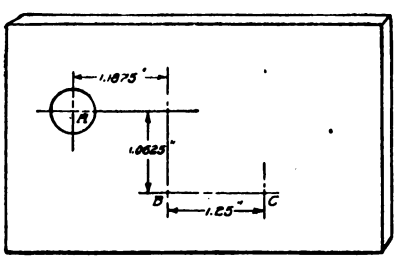


Fig. 276. Location of Bushing Holes in Drill Jig

Making Jig to Model. In the case of a jig that is to be made to a model, the model is exposed if the jig is provided with a leaf, which may be thrown back. Now, by means of a plug inserted in one of the holes, the jig can be accurately located until the sleeve on the stud rings over the plug. The plug can be made with one end a nice fit in the hole in the model, and the other end a nice fit in the sleeve. When the jig is accurately located, the leaf may be closed, and the hole drilled and bored as in the previous example.

Vertical Attachment for Boring Holes. The vertical attachment furnished with the modern universal milling machine provides a means for boring bushing holes in the jigs that for some reason are

found difficult to attach to an angle iron. The jig is clamped to the table of the machine and the buttons located by means of a test indicator, sometimes called a *sweep indicator*. After each button has been located accurately, it is removed and the hole drilled and bored to size.

Boring Holes at Right Angles to Each Other. In the case of jigs having bushing holes on the sides at right angles to each other, the jig can be strapped to the table of the milling machine, and the holes in the vertical portion produced by tools held in the regular horizontal spindle, while those in the horizontal surface can be produced by tools in the vertical spindle. This insures their being exactly at right angles to each other.

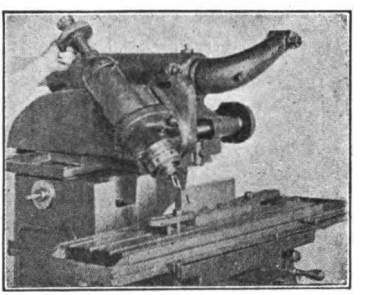


Fig. 277. Milling Machine Attachment for Drilling Holes with Interior Spindle at Same Angle as Milled Surface

Courtesy of Van Norman Machine Tool Company, Springfield, Massachusetts

Boring Holes at Other than Right Angles. At times jigs are made with bushing holes at other than a 90-degree angle to each other. In sueh cases, the jig can be attached to the table of the machine as previously described, and the horizontal, or vertical holes, as the case may be, produced by tools in the horizontal, or vertical spindle; the holes at an angle can be machined by tipping the vertical spindle to the proper angle, locating the position of the holes by buttons and sweep indicator, then drilling and boring them at the desired angle with tools held in the vertical spindle, provided such spindle is equipped with a device for feeding it at the given angle.

Fig. 277 shows a milling machine having an interior spindle, that can be fed at the angle to which the vertical spindle is set.

Method of Locating Jig on Angle Iron. A very satisfactory and convenient method of locating a jig on an angle iron for use on a milling machine in boring bushing holes consists in bolting two good parallels to the face of the angle iron, as shown in Fig. 278.

The parallels may be set at right angles to each other by means of an accurate try square, exactness of position being attained by

the use of draw papers as shown at *aa*. The use of draw papers is to be recommended for many classes of work where extreme accuracy is essential. It is customary to use tissue paper for this purpose and

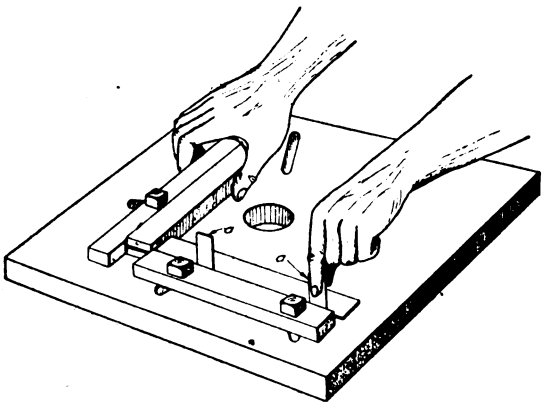


Fig. 278. Attachment for Drilling Holes at Angles

to place a strip of the paper at either end of the square blade, as shown; when the blade rests against the work, the accuracy of the set may be determined by attempting to draw the papers. If one is securely held by contact with the square blade and the other is not held, it is apparent that the pieces are not correctly located. If both pieces of paper are firmly held by contact with the square blade when the beam is securely set against the other piece, it is apparent that the two pieces are exactly at right angles with each other.

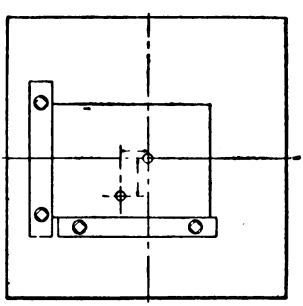


Fig. 279. Layout Showing Parallels Bolted to Angle Iron

The work should now be fastened to the angle iron, with the working edges against the parallels, as shown in Fig. 279, and the machine adjusted until the button that marks the location of the *first* hole to be machined is properly

located. After the first hole has been drilled and bored to size, the jig should be moved to bring the location for the second hole into proper position by placing a thickness block of the proper size between the end parallel and the jig shown in Fig. 280. If no thickness block of the right dimension is available, the jig may be located by means of a plug gage; or a vernier caliper or a piece of wire may be filed to the desired length and used in setting. This assumes, of course, that this hole is the same distance as the first from the bottom edge; if it is on a different plane, the jig must be blocked up from the parallel by means of thickness blocks to bring it to the proper height, as shown in Fig. 281. By this method it is not necessary to use more than one button or to locate the position of more than the first hole. The table and the knee of the machine, being securely locked in position cannot move, and as the jig is moved the exact distance that should separate the holes each time, the holes may be accurately located within a fraction of a thousandth of an inch, which is near enough for most jobs.

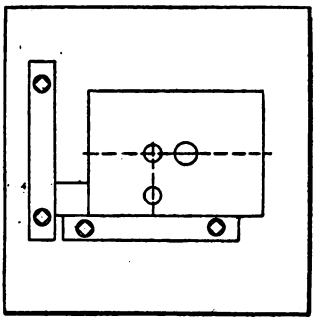


Fig. 280. Set-Up after Boring First Hole

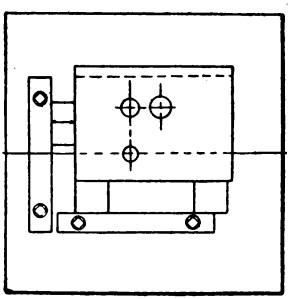


Fig. 281. Another Method for Locating Second Hole

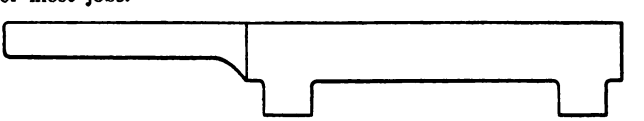


Fig. 282. Cast-Iron Jig with Solid Cast Legs

Jigs with Legs. When jigs are made for permanent equipment, or if they are to be used constantly, it is well to provide some means of elevating them from the drill-press table to avoid inaccurate work

occasioned by chips. If the jig is of cast iron, the legs are sometimes cast solid with the jig, as shown in Fig. 282. In order that the jig handle may be grasped in a manner that will not tire the wrist or

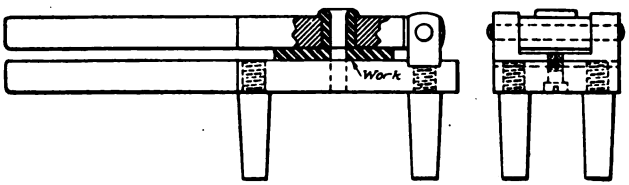


Fig. 283. Jig with Cover

hand, and in order to give sufficient room between the handle and the table of the drill press so that the fingers may not be cut by chips, the legs should be made of a length that will raise the handle about $1\frac{1}{2}$

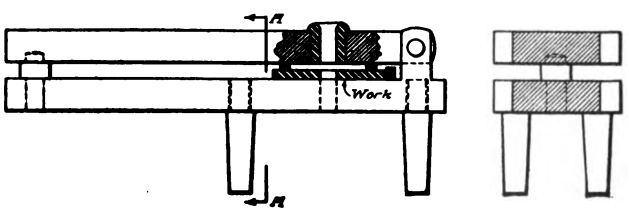


Fig. 284. Covered Jig Showing Space between Work and Leaf

inches above the table. As cast-iron legs of this length would be too weak, it is customary to make the legs of tool steel, hardening the ends that come in contact with the drill-press table.

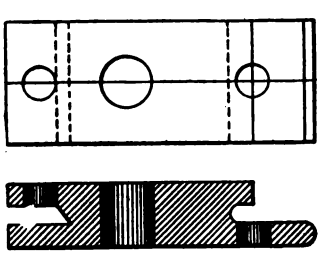


Fig. 285. Jig for Drilling Holes from Both Sides

Jig for Rapid Work. While the form of jig shown in Fig. 256 would give satisfaction on certain classes of work, the process of putting the work into the jig and taking it out would be very slow, as it would be necessary to clamp the work securely to resist the pressure of the cutting tools.

In order that work may be handled rapidly during these operations, jigs are designed so that the work will rest on the base of the

jig as shown in Fig. 283. A leaf or cover containing the bushings can be raised when putting the work in place and taking it out.

When the pieces to be drilled are of a uniform thickness, the leaf may be made to rest on the piece; but should they vary in thickness, the leaf would not be parallel to the base, and, consequently, the hole in the bushing would not be at right angles to the piece to be drilled. For this reason a little space is left between the top of the piece to be drilled and the bottom of the leaf, as shown in Fig. 284;

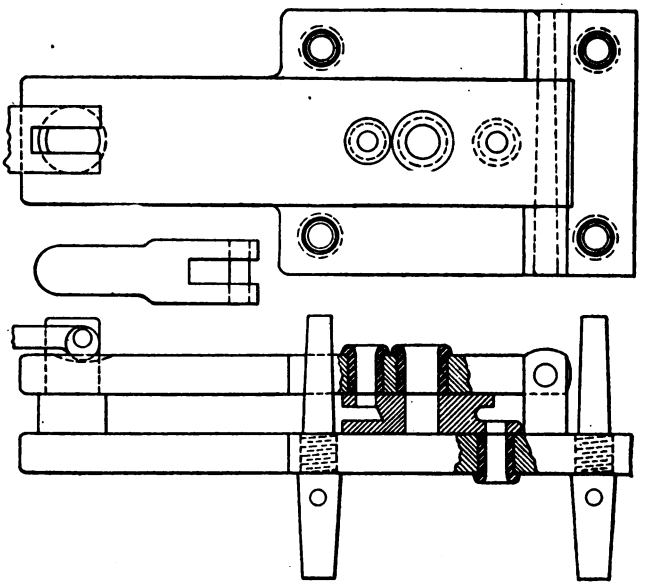


Fig. 286. Jig with Legs on Both Sides

a steady pin having a shoulder is located at the handle end of the jig. The upper end of the pin may project into a hole in the leaf, as shown, thus relieving any strain on the joint of the jig occasioned by the action of the cutting tools.

Jig for Holes on Opposite Sides. When holes are to be drilled from opposite sides of a piece of work, as shown in Fig. 285, a jig may be constructed having legs on both upper and lower sides, but both sets of legs should be solid with the base, as shown in Fig. 286.

If the two end holes in Fig. 285 are of the same size, and it is necessary to use a drill press having but two spindles, the legs on each side must be of a length that will make it possible to set the stops so that the drill will cut the required depth on each side. If a drill press having three or more spindles is to be used, the jig legs may be of a convenient length, as two drills of the same diameter can be used in two different spindles, each one to drill the required depth when the stop is set.

Construction of Legs. Drill jig legs are generally made of tool steel and are screwed into the base of the jig. The thread on the legs should be a good fit in the base. After having been screwed

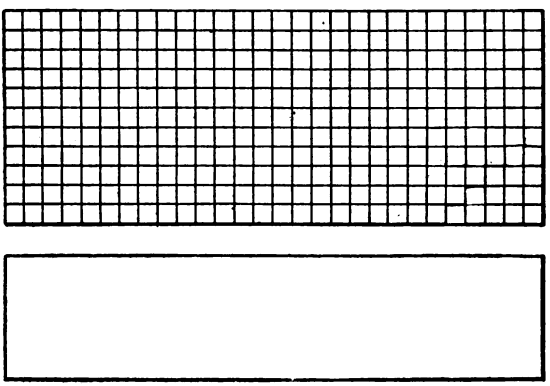


Fig. 287. Flat Lap Block for Lapping Jig Legs

into place, the ends of the legs should be machined to length by milling or planing; the legs can then be removed, and the ends that come in contact with the drill-press table hardened. The legs should now be polished, if that is allowed, and screwed into place. The ends are then ground to such a length that the surface where the work is seated will be of the correct height above the drill-press table.

Grinding the ends of the legs can best be done in a surface grinder, or some form of universal grinder designed for surface grinding. After grinding, the ends of the legs should be lapped to remove any irregularity that may result from grinding. A very good lap may be made from a flat plate or block of cast iron. The surface to be used should be planed flat and smooth, then a series of grooves cut

to form squares, as shown in Fig. 287. These grooves should be cut with a V-shaped tool and should be $\frac{1}{4}$ inch apart, and $\frac{1}{64}$ inch to $\frac{1}{32}$ inch deep. The grooves catch the emery and feed it to the work being lapped. If the pressure is not equal, one leg may be cut shorter than the other, or may be lapped out of true, causing the jig to rock.

Jigs with Cored Holes. As large jigs are usually made from cast iron and as it is advisable, when the holes are large, to core them, it is necessary, in order to lay off the location of the center of the hole, to insert a piece of steel or brass *a*, Fig. 288, in the hole and then to determine the desired point on the inserted metal.

Where the button method is to be used, a button of a size somewhat larger than the cored hole is required; and this, bolted against the face of the boss in the proper location, enables the workman

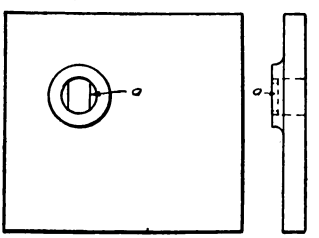


Fig. 288. Locating Center of Cored Hole in Jig

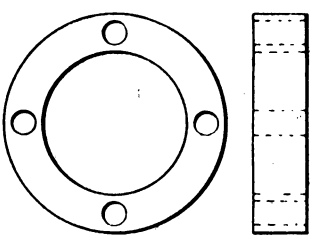


Fig. 289. Use of Buttons in Using Bore Bar for Bushing Holes in Jig

properly to locate the jig on the faceplate of the lathe. If the jig is too large to swing in the lathe, it may be fastened to the table of the boring mill and trued by means of an indicator held in the cutter head of the machine; or the jig may be attached to the milling machine table, and the bushing hole bored, as described on previous pages.

When properly located, the piece of brass and steel may be knocked out of the hole, or the button may be removed and the hole bored to desired size. Many tool-makers always drill or file the walls of a cored hole to remove all hard scale, as there is always more or less danger of knocking a piece of work out of true when cutting through cast-iron scale. When the scale is removed before machining, there is little likelihood of moving the work if it is securely clamped to the machine, and the workman is reasonably careful.

In work of this character, the workman is not expected to take such heavy cuts as would be taken on manufactured articles which are securely held in specially designed holdfasts; and he should be particularly careful when taking cuts where there is more stock to be removed on one side than on the other, as the unequal strain is especially likely to throw work out of true.

The warning given elsewhere should be repeated: *Never ream a bushing hole;* always machine to size with an inside turning tool, or with a boring bar where such a tool can be used.

Under certain conditions, especially where a boring bar is to be used, either in the boring machine or in a lathe where the work is to be fastened to the carriage and the boring bar supported on the centers of the lathe, buttons are used which have several holes passing through them, as shown in Fig. 289. These holes are somewhat larger than the cap screws which attach the button to the face of the jig. The button has a hole through the center $\frac{1}{16}$ or $\frac{1}{8}$ inch larger than the desired hole in the jig. It is accurately located on the face of the jig, which is then placed on the machine and fastened in position. To locate the jig properly, the boring bar is passed through the cored hole and placed in position; then by fastening an indicator to the lathe spindle and rotating the latter, the button can be set so as to be equidistant at all points from the bar. This method will compensate for any eccentricity in the boring bar.

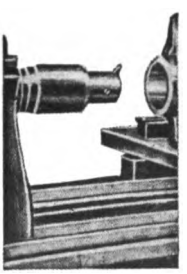
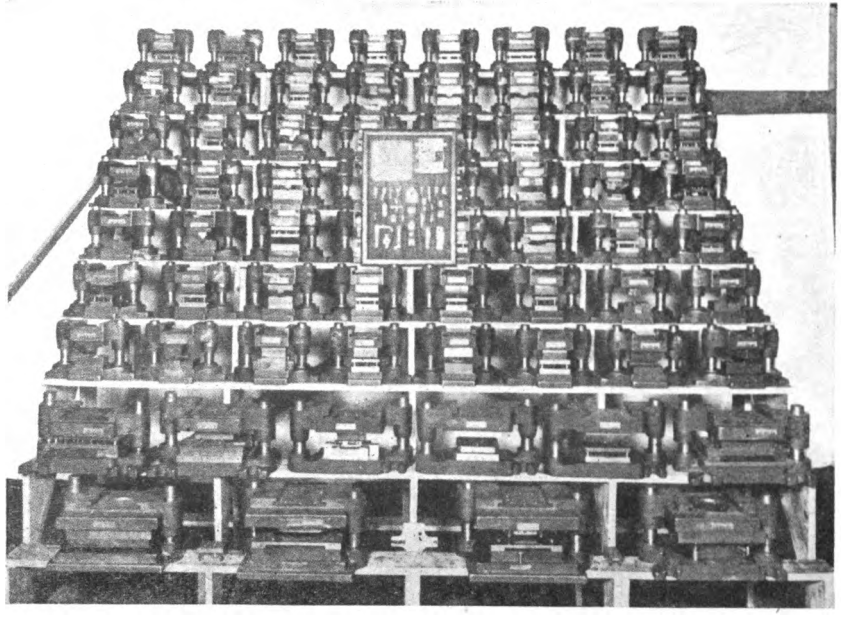


Fig. 290. Boring Cutter for Holes Which Passed Partly through Jig

The advantage of this form of button is that it can be left in position on the jig while the hole is being bored; and when the hole is finished, a plug may be inserted, and the hole tested for accuracy of location.

At times, it is desirable to use the method described above when the hole passes through but one side of the jig and it would not be possible to carry it through the other side. In such a case, a boring tool which screws on the nose of the spindle or fits into the spindle hole may be used. Such a cutter is shown in Fig. 290.



MODERN SET OF TOOLS MADE FOR THE ADSIT TELEPHONE LOCKOUT COMPANY
Courtesy of H G. Saal Company, Chicago, Illinois

TOOL-MAKING

PART III

STANDARD TOOLS

DRILL JIGS

Fastening Devices. Various devices are used to fasten the leaf of a jig to hold the work in place, or to clamp the leaf in position. The forms used depend upon the class of work being operated on.

If the leaf must be fastened solidly, and the amount of time consumed is not of great importance, some form of *screw clamp* may be used; but if the work must be handled rapidly, the clamping device is generally operated by some form of cam. However, a screw

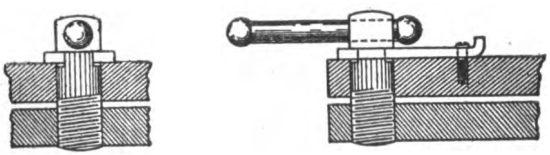


Fig. 291. Screw Clamp for Jig

clamp may be designed to work quite rapidly, and such a one is illustrated in Fig. 291. This screw clamp consists of a screw with a hole drilled through it to receive a pin that is used as a lever to operate the screw. The screw is necked $\frac{1}{16}$ inch deep, the necking being $\frac{1}{8}$ inch wide; a flat washer is attached to the leaf of the jig by a small screw, as shown. A slot the width of the screw is cut in this washer to allow it to slide back and forth, and in the end of the washer is a slot the width of the bottom of the necking in the screw. The other end of the washer is turned up, as shown, to furnish a means of pushing back and forth. When the jig leaf is closed, the washer is pushed forward and the ends engage in the slot in the screw. One turn of the screw binds it very tightly. When the screw is given one turn to loosen it, the washer may be pushed back and the jig leaf raised.

Where it is not necessary to use much power, but extreme rapidity of action is desired, a *hinged cam lever* of the design shown in Fig. 292 may be used. The cam lever is pivoted to the base of the jig by means of a pin as shown. The lever passes into a slot

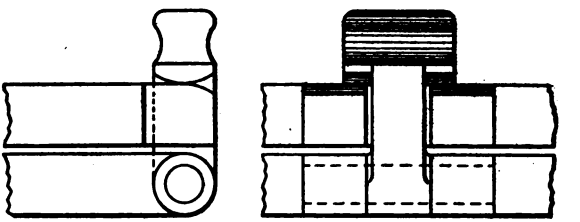


Fig. 292. Hinged Cam Lever for Jig

in the leaf, and the bearing surfaces on the under part of the head come in contact with the inclined surfaces at the end of the leaf.

Bushings. Bushings of hardened tool steel are made as a permanent guide for the cutting tools. The hole in the bushing is made to fit the cutting tool that is to be guided. There are various forms of bushings; the plain straight form, Fig. 293, is sometimes used, but is objectionable because it may be pushed into the jig if the cutting tool is too large to pass through the hole. To overcome this tendency, bushings are sometimes made tapering on the outside, as shown in Fig. 294; but as this is an expensive form, and as it is an extremely difficult operation to bore the bushing hole in the jig, it is not generally used for permanent bushings.

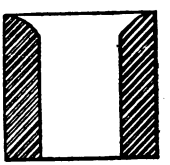


Fig. 293. Bushing with Straight Outside

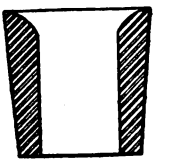


Fig. 294. Bushing with Tapering Outside

The most common form of bushing is straight, with an enlarged portion or head. When no allowance is made for grinding on the outside, the bushing is usually made in the form shown in Fig. 295. If the shoulder under the head is square, it is likely to crack at the sharp corner, or the head may be broken off when being forced into position. In order to avoid these difficulties, a fillet is left under the head, as shown in Fig. 296.

Grinding. When it is essential that the location of the drilled hole or portion of the piece being machined in the jig be exact, the tool must fit well in the bushing; and as the size and shape of the bushing are likely to change in the hardening, it is advisable to leave enough stock to grind to size, both inside and out. It is essential that the outside of the bushing be exactly concentric with the inside. After the hole is ground and lapped to size, the bushing may be placed on a mandrel which runs true, and the outside ground to size. When machining a bushing which is to be ground on the outside, it is necessary to neck in, under the head, as shown in Fig. 297, in order that the emery wheel may pass entirely over the part being ground and insure a straight surface. The under side of the head which

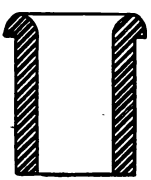


Fig. 295. Common Bushing

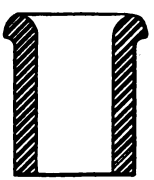


Fig. 296. Bushing with Fillet under Head

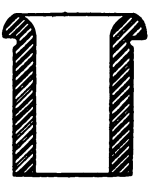


Fig. 297. Necked Bushing

rests on the upper surface of the jig should be ground so that it may be true with the surface of the jig.

When grinding a bushing, a mandrel should be used which is straight or of very slight taper and has been tested for trueness. If the taper is considerable one end of the hole in the bushing will not fit, and the outside of the bushing will not be concentric with the hole. Consequently, no matter how careful the tool-maker may be in laying out his work and in boring the holes for the bushings, the jig will not be accurate.

Size of Bushings. The outside diameter of a bushing is often determined by the design of the jig; for instance, two holes are often located so near each other that it is impossible to make the bushings much larger than the holes through them. Whenever possible, the outside diameter should be made enough larger than the hole to leave a reasonably thick wall. A bushing with thin walls is likely to close in when being pressed to its seating; also, if a cutting tool binds in a bushing with thin walls, the bushing turns in the jig.

Removable Bushings. It is sometimes advisable to perform two or more operations in the same jig. After a hole has been drilled, it may be that it will be considered good practice to counterbore or tap it, or, possibly, it may be better to do the three operations while the work is seated in the jig. In such cases the bushing having a hole the size of the drill must be removed, and one inserted that has a hole fitting the tool to be used.

A very simple way of making a removable bushing consists in boring the hole in the jig large enough to receive a hardened bushing with a hole the size of the outside of the bushing to be used. If the hole in the large stationary bushing and the outside surface of the removable bushing are lapped smoothly after grinding, they

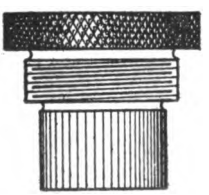


Fig. 298. Threaded Bushing

Fig. 299. Removable Bushing, Threads Run Entire Length

may be used for a long period before wearing enough to affect appreciably the location.

Tapered removable bushings are sometimes used, but on account of the expense of producing them, and the fact that chips and dirt readily throw them out of their true locations, they are not very common and their use is not advised.

Fig. 298 shows a form of removable bushing threaded on the outside to fit a threaded hole in the jig. If the thread on the outside of the bushing runs the entire length, Fig. 299, the process of screwing it in and out of the jig is necessarily very slow; consequently it is advisable to have but a few threads. The balance of the length may be made to fit a bearing in the jig. If it is advisable to thread the entire length, the hole should be ground true with the thread to prevent change of shape in hardening. As it is not well to attempt to grind between the lands of the thread with the facilities in the ordinary machine shop, it is necessary to grind the hole true with the thread. This can be done satisfactorily by placing a piece of

stock in a chuck on the lathe having a grinding attachment. After drilling and boring the hole to tapping size, the thread should be chased so that the bushing is a good fit in the hole. It can then be screwed in, and the hole ground to size.

Box Jig. If the piece of work is of a shape that makes it necessary to operate on all sides, and the outline prevents the use of a clamp jig of the form shown, a box jig must be used. A box jig is made in the form of a box, the piece being located in the jig by means of stops or locating points which differ according to the nature of the work. It is often advisable to design this form of jig so

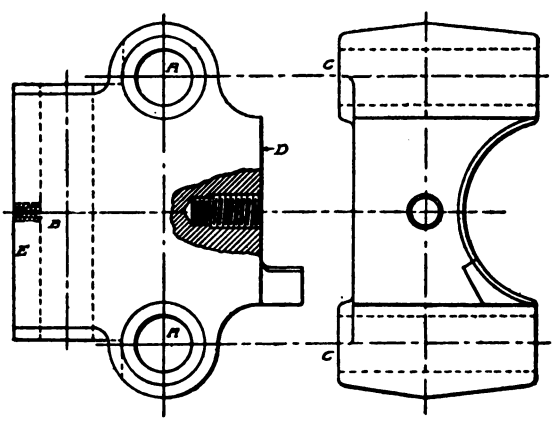


Fig. 300. Special Piece to Ce Drilled

that all holes in the work can be drilled at one setting; that is, if there are twenty holes in the piece, it is designed to allow the drilling of them all while the piece is in the jig. For other work it is advisable to make two or more jigs to drill the holes; this is the case when some part of the piece is to be machined after one or more holes are drilled, but before drilling the others.

In Fig. 300 a piece of work is shown (about three-eighths size); through the piece it was necessary to drill three 1-inch holes as shown at *A*, *A*. and *B*. As the holes *A A* must be an exact distance from *B*, it was found by experience that much better results could be obtained if the hole marked *B* was drilled and reamed in a jig,

the piece taken out of the jig, and the portions marked *CC* milled in exact relation to the hole *B* and as nearly as possible at right angles with the side of the casting marked *D*. After the portions *CC* had been milled, the piece was placed in another jig, locating it by the hole *B* and the surfaces *CC;* the holes *AA* were then drilled and reamed. In order to drill the hole *B*, the jig shown in Fig. 301 was used. The piece was placed in the jig with the rounded surface *E*, Fig. 300, resting in two V-blocks, *A*, Fig. 301.

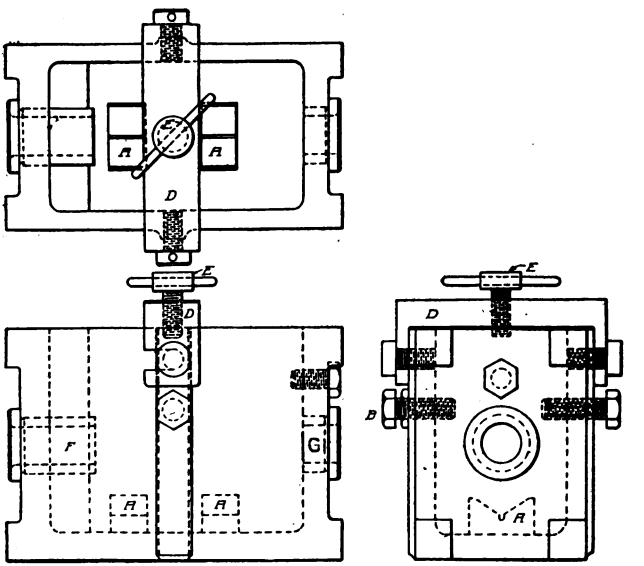


Fig. 301. Jig for Work Shown in Preceding Figure

It was located by means of the fixed stop screw *B*, and forced against *A* by the screw; it was held in position by the screw *E*, which was located in the strap *D*, this strap being removed when putting a piece of work in the jig or taking it out. As it was necessary to have the hole straight and true with the locating points, it was reamed with a single-lip reamer having a pilot, Fig. 302. The hole was drilled somewhat smaller than finish size ($\frac{1}{64}$ inch), and the reamer was entered in the hole, the pilot fitting the bushing *G*. While

the body of the reamer fits the bushing F, as previously explained, the single-lip reamer acts on the same principles as a boring tool used in the engine lathe, the result being a hole straight and true.

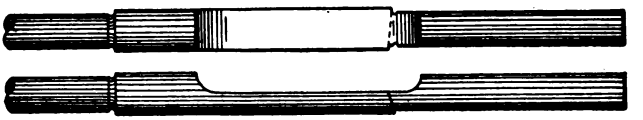


Fig. 302. Single-Lip Reamer with Pilot

As it was necessary to have the hole in the upper bushing of the size of the body of the reamer, and as a drill $\frac{1}{64}$ inch smaller than this size must be used, it was advisable, in order properly to start the drill, to use a transfer drill, shown in Fig. 303, the cutting portion *A* being the size of the drill to be used in making the hole, while *B* fitted the hole in the bushing. By means of this drill, a hole the size of the drill to be used was started in the casting, perfectly true with the hole in the bushing, yet somewhat smaller. When the hole had been drilled to a depth of $\frac{3}{16}$ or $\frac{1}{4}$ inch, the transfer drill was removed, and a twist drill of the proper size used to finish. When the piece of work was taken from the jig, the portions marked *CC*, Fig. 300, were milled as explained. The piece was then placed in another jig, and a pin fitting the reamed hole passed through the locating bushings and through the hole; by this means the other two holes could be accurately located and drilled. The second jig so closely resembles the first that it is unnecessary to illustrate it.

Jig for Holes around Circular Shaped Pieces. At times, it is essential to design a drill jig for drilling holes, either equally or

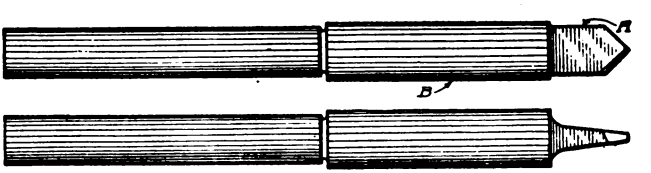


Fig. 303. Transfer Drill

unequally spaced, around a circular shaped piece of work, such as the six equidistantly spaced holes around the circumference shown in Fig. 304. These holes are all radial; but a jig of this type

may be designed to drill holes that are not radial, or it may be designed to drill a number that are radial and others that are not

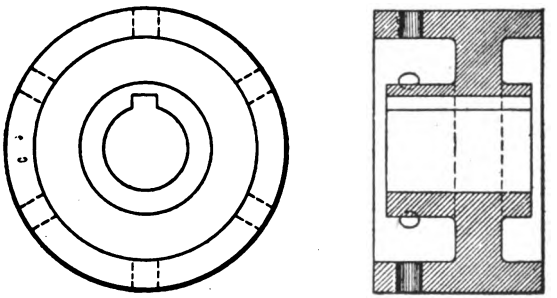


Fig. 304. Drilling around Circular

radial by locating the bushings to produce the holes in the desired locations.

Fig. 305 shows a jig with but one bushing designed to drill the six holes in the piece shown in Fig. 304. The spacing of the holes is determined by the index plate *A*, while the work is held on the stud *B*. As the holes must be accurately located with the keyway in the piece, the stud in the jig is provided with a key to fit the keyway. The dial plate being keyed to the stud *B*, the holes

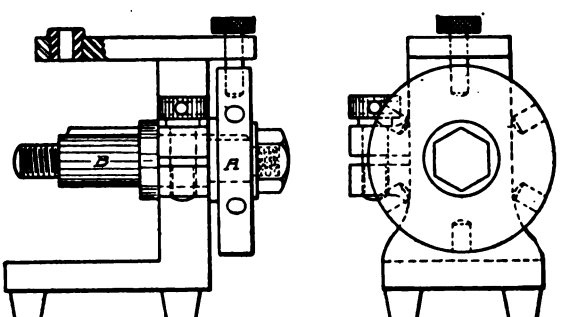


Fig. 305. Jig with One Bushing to Drill Six Holes

drilled in any number of pieces will all exactly correspond with the location of the keyway and with the holes in all of the other pieces.

While the dial shown on the jig in Fig. 305 is designed to drill six evenly spaced holes, the holes in the edge to receive the locating pin might have been cut in any desired number and have been spaced to produce holes of an uneven distance apart.

If large drills are to be used in connection with the jig, it is advisable to provide some method of binding the stud to prevent any strain on dial and pin for such a strain would tend to render the jig inaccurate after it had been used for a time.

In the case of the jig shown, the portion of the body of the jig that provides a bearing for the stud is split and supplied with a binding screw and lever. The stud should be securely locked in position each time the piece is turned to locate a hole to be drilled.

If holes are to be drilled at different distances from the shoulder, two or more bushings may be provided. If the holes are all of one size, such an arrangement of bushings may lead to error unless the locating hole on the dial is so stamped that the operator can by looking at it as the pin enters, see which bushing the drill should enter.

This form of jig is capable of almost endless variation of design, and can be made to accommodate not only pieces that are round in form, but those of almost any form where holes are to be drilled around the outer surface. In some shops the work is of such form and the holes are so arranged that many jigs of different design are not necessary, but all of above types are used.

PUNCH AND DIE WORK

Dies. A die used for punching a blank from a sheet of metal is termed a blanking die, and is generally considered as belonging to one of three classes: plain (or simple) die, gang die, or compound die.

A set of blanking dies consists of a male die, or *punch*, and a female die, or *die block*. The die block is that part of the die which has a hole of the same outline as the desired blank; the male die, or punch, is of a shape that fits the impression or hole of the die block.

When punching work on a punching press, the stock is placed on the die and the punch forced through it into the die; this drives a piece of stock of the same outline as the hole down into the die

block. As the punch is forced through, the metal in the sheet has a tendency to close on the punch and to be raised by it. In order to prevent this, the die block is provided with a *stripper plate*, or *stripper*, which is fastened to the die, or to a shoe holding the die, at a height that allows the metal to be punched to pass freely between it and the die. The stripper must be strong enough to force the stock from the punch without springing, especially if the punch is slender and the stock thick, for if it did not, the punch would be sprung or broken.

In order to guide the stock over the die and leave the proper amount of margin or scrap at the edge of the sheet, a *guide* is furnished. The guide is usually made of stock sufficiently thick to bring the stripper the proper height above the face of the die. A *gage pin*, or *stop*, is usually provided, so located that the proper amount of scrap is left.

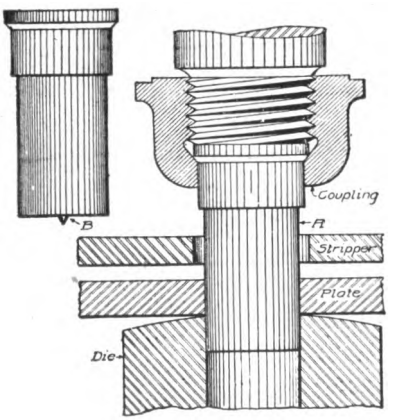


Fig. 306. Punch for Boiler Plate Showing Locating Point

Boiler Plate Punches. Punches for use on boiler plate and similar material are made with a locating point as shown at *B*, Fig. 306. This point enters a prickpunched mark, and so locates the sheet for punching. The workman lays off and prickpunches the sheet where each hole should be; the sheet is then taken to the punch press, and each hole is punched as laid off.

Punches for Large Holes. In Fig. 306, *A* is the form generally used for punching large holes, or for heavy material. If the face of the die is made flat, it is necessary to shear the punch. The die is made round in form, as shown, and is held in the bolster by means of a round-end set screw which enters a cut on the side of the die near the bottom.

In Fig. 307, *A* is the die block, *B* the hole through the die block of the shape of the piece to be punched, *C* the stripper, *D* the guide, and *E* the gage pin or stop.

Die Holders. Dies are held in position on the punching press bed by various methods, the most common of which are the forms

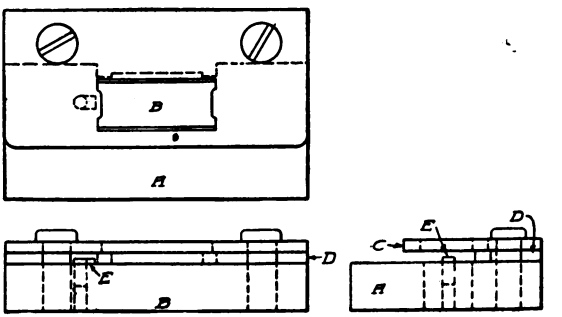


Fig. 307 Punching Die

of holdfast shown in Figs. 308 and 309. These die holders are known by various names, such as chair, bolster, and chuck. Large dies are clamped to the bed of the press.

Dies are usually beveled on the edges that come in contact with the die holder, to prevent their rising from the seat. The angle given to the edges varies according to the ideas of the designer. An angle of 10 degrees from the vertical gives satisfaction, although some mechanics insist on an angle of 15 degrees or even 20 degrees.

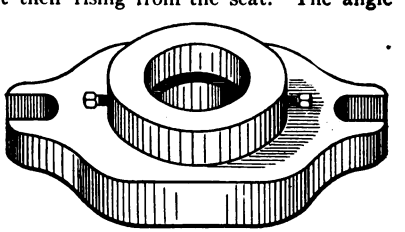


Fig. 308. Form of Holdfast

Fig. 310 shows a die holder with a die whose edges are at an angle of 10 degrees; the die is held in place by set screws. It is generally considered advisable to place a gib, or shim, between the set screws and die as shown. Sometimes the gib is omitted, and then the set screws bear directly on the edge of the die. Some

tool-makers prefer a die holder without set screws, and hold the die securely in place by the gib, which is made wedge-shaped and is driven to place.

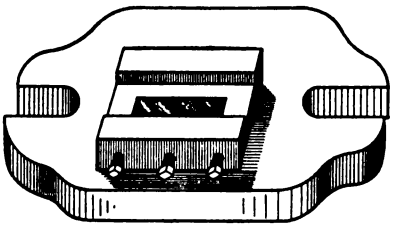


Fig. 309. Form of Holdfast

Fig. 311 shows a method of holding dies which allows them to be easily set in position when rigging up. The die is placed on the seating of the die holder, and brought to the proper position. The set screws are then brought against the edge of the die, or against strips of steel which are placed between them and the edges of the die.

Making Die. *Preparation of Bar.* When making several dies of equal width and thickness, a good method is to plane the two sides of a bar to remove the outer surface and to bevel the edges to the required angle. Pieces can then be cut off to any length wanted.

Fig. 310. Die in Holder

The upper surface of the die bar may be finished smooth by planing with a smoothing tool; it may be ground in a surface grinder, or it may be finished with a file. It is necessary to have the surface smooth in order to lay out the correct shape of the hole; a roughly machined surface would allow neither distinct nor correct work. The die must be laid out in such a manner that the stock may be readily fed to it. If the grain of the stock is a matter of importance, as in making a tempered spring, the worker must take care to see that the grain runs in the proper direction

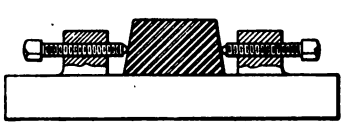


Fig. 311. Easily Set Die Holder

Marking and Drilling. The face, or upper surface, of the die is covered with the blue vitriol solution, and the outline of the piece to be punched is laid out. After the die has been carefully laid

out from a templet or drawing, all round corners should be drilled with a drill of proper size; they are then reamed from the back side of the die with a taper reamer to give the desired clearance, and the balance of the stock is removed by drilling, as shown in Fig. 312.

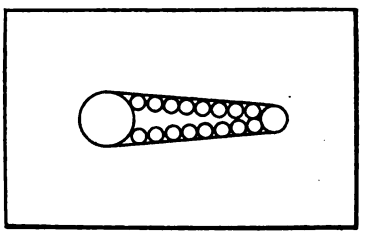


Fig. 312. Removal of Stock by Drilling

The method of removing the center, or core depends on the custom practiced by the individual die-maker. One die-maker may drill the holes so that they break into one another, and for him the best tool is a straightway (straight fluted) drill. Another will drill small holes and use a counterbore to enlarge to size, the counterbored holes breaking into each other. Usually the holes are drilled with at least $\frac{1}{64}$ inch to $\frac{1}{32}$ inch between them, and the intervening stock is cut out with a flat-ended hand broach, Fig. 313. Generally speaking, the last mentioned method is the safest and quickest.

Milling. After the center has been removed, the die may be placed in a die milling machine or a die sinking machine; and by the use of a milling cutter of the proper taper, the desired angle of clearance can be given. The amount of clearance varies with the nature of the work to be done.

When a die is milled on a die milling machine of the form shown in Fig. 314, the cutter spindle is underneath the die, the face of which is uppermost; consequently the milling cutter can be made largest at the shank end of the cutting part, the required taper

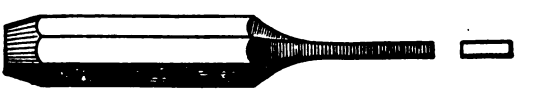


Fig. 313. Flat-End Hand Broach

being given as shown in Fig. 315. If the outline of the hole is milled on a die sinking machine, it is necessary to use a cutter of the shape shown in Fig. 316, in order that the face of the die having the lines will be uppermost.

Filing. After working the impression as near to shape as possible by milling, it can be finished by filing. In order to give the die the proper clearance, the walls should be gaged with a bevel gage of the form shown in Fig. 8, Part I. As the clearance differs in various shops, and on different classes of work, no stated amount can be given for all cases; it varies from $\frac{1}{4}$ degree to 3 degrees. The latter is excessive, and is seldom given unless it is necessary that the piece punched drop from the die each time.

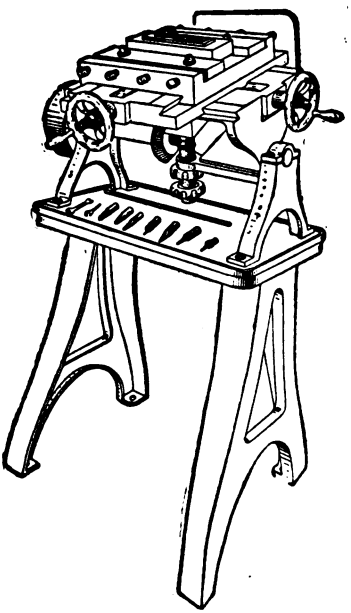


Fig. 314. Die Milling Machine

If the die is milled as just described, it will be necessary to work all corners to shape with a file. If a universal milling machine having a slotting attachment is used, the corners can be properly shaped and the necessary clearance given by using suitably shaped cutting tools, and turning the fixture to the proper angle.

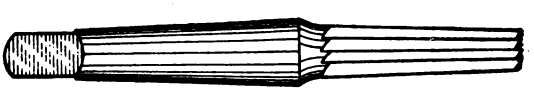


Fig. 315. Die Milling Cutter

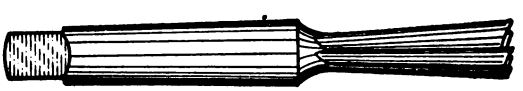


Fig. 316. Cutter for Die Sinking Machine

Fig. 317 shows a slotting fixture attached to a universal milling machine; while Fig. 318 shows a fixture known as a die shaper, which is also attached to a milling machine.

Die Filing Machine. In many shops the die filing machine, shown in Fig. 319, is used for many of the operations of working to shape dies, gages, templets, and various small parts. It is also used in lapping dies, gages, and models, which have been hardened. As the table of the machine can be set at an angle, dies can be filed or lapped at the proper angle to give the desired clearance.

A saw may be used in place of the file, and the core of the die sawed out, this is a very satisfactory way of cutting the core from a small die having an irregularly shaped opening, whose outline

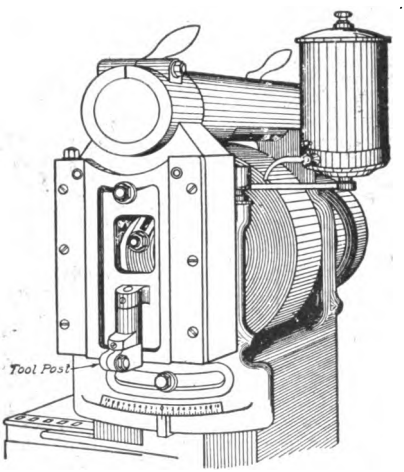


Fig. 317. Slotting Fixture on Universal Milling Machine

is such that the ordinary methods do not prove satisfactory, or are extremely costly. For large work, an ordinary hack saw blade may be used, holes being drilled at the corners of the openings. For small work and where irregularly shaped openings are to be produced, a narrow blade whose teeth have quite a little set is advisable.

For roughing out a die opening, a coarse file should be used, the file being clamped at either end, and the work held against it by means of the feed screw, while the die is guided by hand. When taking finish cuts with small files, the file is usually held in the lower clamp only. As the file clears on the return stroke, undue

wear is avoided. The crank pin may be set at either end of the crank arm, as may be desired, so as to cause the file to cut at either the up or down stroke.

Graduated table readings are furnished so that the table can be set to provide any angle of clearance. The surfaces produced by this machine are flat, and especially adapted to dies having but a

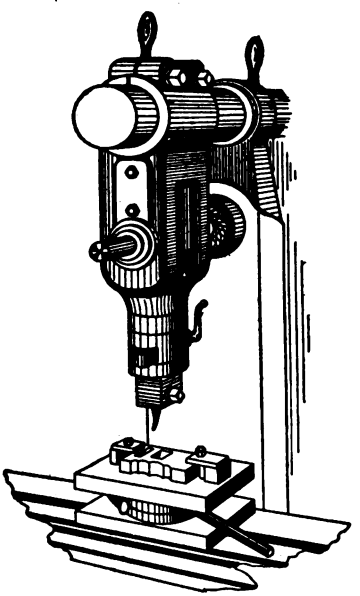


Fig. 318. Die Shaper

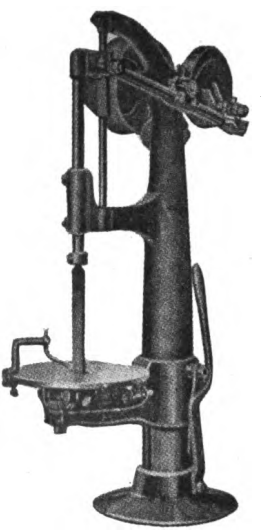


Fig. 319. Die Filing Machine for Filing and Lapping Dies, Gages, etc.

small clearance angle where any rounding of the surfaces would not be allowable.

Shearing. Die blocks have their cutting edges beveled in order that the blank may be cut from the stock by a shearing cut. Shear is given the face of the die to reduce the power necessary to cut the blank from the stock, so that a thicker blank can be cut. The shear also reduces the strain on the punch and die.

The face of the die is sheared when the blank, or piece forced through, is the product to be saved. But if the piece surrounding the blank is to be saved, and the blank is of no use, the face of the die is left perfectly flat and the end of the punch is sheared

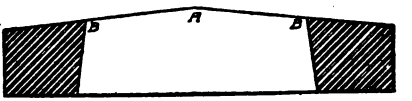


Fig. 320. Die for Punching Heavy Spring

The cutting face of the die may be sheared by milling or planing to the desired angle, depending on the thickness of the stock to be punched and also on the power of the press. A common method of shearing a die is shown in Fig. 320, which shows a section of a die used for punching a heavy spring. The end of the punch is left flat. The punching, commencing at the center *A*, is continued with a gradual shearing cut as the punch descends until it reaches the

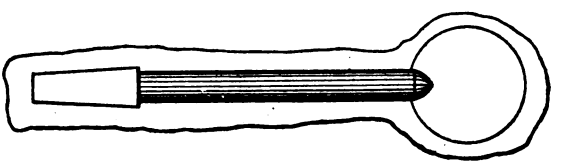


Fig. 321. Forging Requiring Extra Amount of Power

ends *BB*, of the opening. The blank punched will be straight, but the stock will bend somewhat unless it is quite stiff, in which case it springs back to shape when the pressure is removed.

When the punching requires an amount of power in excess of the capacity of the press, as in the case of the forging shown in Fig. 321, it is necessary to trim the flash occasioned by the process

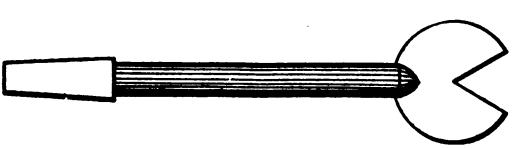


Fig. 322. Piece Forged and End Punched at Same Time

of drop-forging, and at the same time to punch the end to shape, as shown in Fig. 322. It is obvious that the material removed is not the valuable part, and, as it is necessary to use a light press,

the die may be given a shear as shown in Fig. 323, thus making it possible to do the punching on a press whose capacity would not be equal to the job if the die had been sheared as shown in Fig. 320.

Fig. 323. Shearing Die for Preceding Piece

In order to facilitate the operation of grinding the face of a die, it is frequently made with a raised boss around the hole as shown in Fig. 324.

Sectional Dies. In order that dies may be worked to shape more easily, they are sometimes made in two or more pieces which are fastened together when in use. The plain die, Fig. 325, is made in two pieces, which are held in their relative positions by the dowel pin at each end, shown at *A* and *B;* when in the die holder, they are held together in such a manner that they cannot spread.

Dies of this form should have the surfaces that go together finished true; the pieces should then be clamped together, and the dowel pin holes drilled and reamed. They should then be taken apart and any burrs caused by drilling and reaming removed. The pins should now be inserted, and the top and bottom of the die planed. The outlines of the piece to be punched are next laid out, and the round hole at one end drilled, after which it should be reamed from the back with a taper reamer to give clearance. The die is then taken apart, and the opening cut out on the planer or shaper, the sections of the die being held at the proper angle to give the desired amount of clearance. After the two pieces have

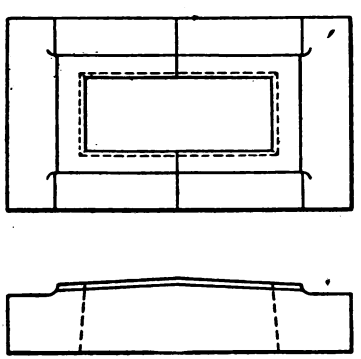


Fig. 324. Boss around Hole for Grinding

been put together, the opening may be finished to the templet with a file and scraper.

To hold the die together securely, it is necessary to use a die holder of the form shown in Fig. 326. The die is represented in

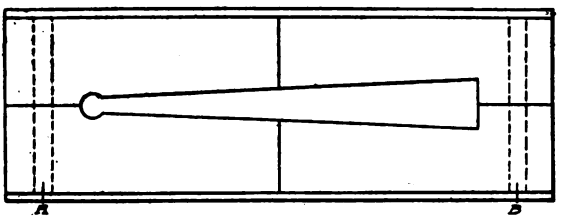


Fig. 325. Two-Piece Die

place in the holder, which is held in the bolster, this being in turn attached to the bed of the press. When the die is finished to the templet, and the proper clearance given, make sure that the walls

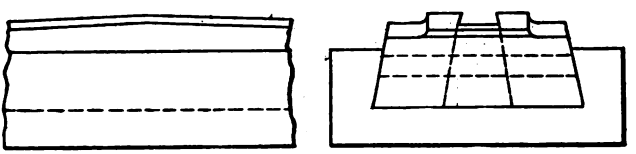


Fig. 326. Die Holder

of the opening are straight (not crowning), although it is not always considered advisable to carry the clearance to the edge, as the size of the opening would then increase every time the die was sharpened. In such cases the clearance extends from the bottom to within a short distance (about $\frac{1}{8}$ inch) of the cutting surface, as shown in the sectional view, Fig. 327. In this figure the clearance is exaggerated to illustrate the idea more plainly.

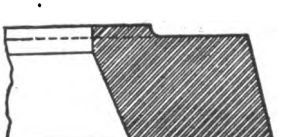


Fig. 327. Clearance of Dies Exaggerated

The walls of the upper part of the opening are at right angles to the base of the die; but they must be straight (not crowning) because if the opening is wide enough to allow the punch to pass through the crowned part, the

stock would, if thin, be likely to leave the blank with ragged edges which would extend up on the sides of the punch and have a tendency to burst the die.

Hardening Dies. *Applied to Ordinary Shapes.* Before hardening, the stripper and guide screw holes should be drilled and tapped, and the hole drilled for the gage pin or stop. If the name of the part to be punched, or the shelf number of the die is to be stamped, it should be done now. After all screw holes, stop-pin holes, etc., are filled with fire clay mixed with water to the consistency of dough, the die is ready for hardening. Extreme

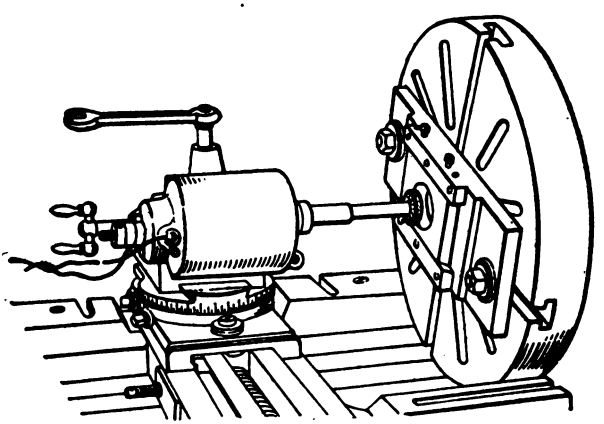


Fig. 328. Grinding Round Opening in Die

care should be exercised in the heating; the heat must be no greater than is absolutely necessary, and it should be uniform throughout—the corners of the die must be no hotter than the middle of the piece, and the outside surface must be of the same temperature as the interior of the steel. The water in the bath should be slightly warmed to prevent any tendency to crack. The die should be lowered into the bath and swung back and forth gently so that the bath may pass through the opening and harden the walls. As soon as the singing ceases, the die should be removed and plunged into a tank of oil and allowed to remain until cold, when it is brightened and the temper drawn. If more

than a few minutes are to intervene between the time the die becomes cold and the time for commencing to draw the temper, the die should be held over a fire or placed where it can be heated, to remove the internal strains which have a tendency to crack the piece.

When there is a heavy body of metal around the openings in a die, and a light partition between the openings, there is danger of cracking during the hardening. In such cases it is frequently possible to apply a little oil to the light portion, especially at the point where it connects with the heavier portion, thus preventing too rapid cooling of the parts, and so doing away with the danger of cracking. The oil may be applied by means of a piece of cloth, which may be attached to a wire; in this way the oil reaches the desired spot and no other. The oil having been applied, the die may be cooled in the bath in the usual manner.

Applied to Special Shapes. When a die of such a shape that it is likely to give trouble, is to be hardened, much more satisfactory results will follow if the pack-hardening process is used. Run the dies from one to five hours in the fire after they are red hot; then dip them in raw linseed oil and swing them back and forth to force the oil through the opening. Dies having openings that are perfect circles may be left a trifle small until after hardening, when they are ground to exact size as shown in Fig. 328. Here the die is held in a chuck and the grinder is motor driven.

Tempering. A very common method of drawing the temper of dies and similar pieces, is to heat a piece of iron to a red heat and place the hardened piece on it, leaving the face of the piece uppermost. Experience shows, however, that this method of treatment is too harsh for hardened steel, especially if the job is in the hands of one not thoroughly experienced, for it subjects one side of the piece to an intense heat while the opposite side is exposed to the cooling effects of the air. If an open fire is used, a plate may be set on the fire, and the die placed on the plate before it is hot; now the temperature of the plate may be raised gradually, the die being turned occasionally. In this manner, the temper can be drawn to the desired degree with safety. When such a fire is not available, two plates may be used, one heating while the other is in use. The first one should not be very hot, the next somewhat hotter, and so on until the die is drawn to the desired color.

Punches. The punch is used to force the metal through the die, thus producing pieces of the desired shape.

In the case of small plain dies, the punch is generally made of the form shown in Fig. 329. The end *A* is of the same outline as the opening in the die; the shoulder *B* which bears against the shoulder of the punch holder, takes the thrust when the punch is working; the shank *C* fits the hole in the punch holder or in the ram of the press. It is customary in most shops in this country to make the die to a drawing or a templet, and then to harden it, after which the punch is fitted to it.

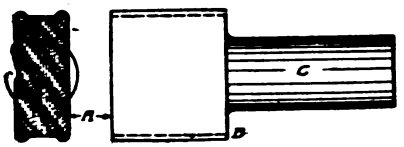


Fig. 329. Plain Punch

Laying Out. The templet may be used in laying out the punch for a plain die. If the shape of the opening in the die is the same on each side, Fig. 330, and the die does not change shape in hardening, either side of the templet may be used next to the face of punch; but if the outline is of the form shown in Fig. 331, it will be necessary to exercise care to see that the proper side is used, because the side of the templet placed against the face of the punch

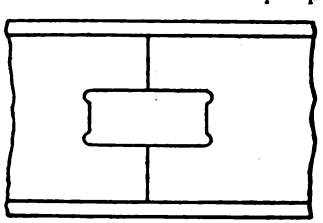


Fig. 330. Typical Die of Same Shape at Both Ends

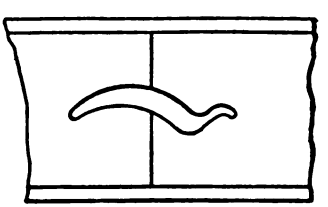


Fig. 331. Die of Odd Form

when laying it out will be opposite to the one placed against the face of the die when laying that out.

In order to obviate this trouble, many tool-makers lay out the face of the punch from the opening in the die before beveling the face for shear. In order to hold the punch and the die together so that there will be no danger of the punch slipping while the shape is being transferred, a die clamp of the form shown in Fig. 332 should be used.

Machining to Shape. The punch blank should be machined on both ends, and the shank turned to size. The end which is to fit in the opening in the die should be finished with a smooth, flat surface, and colored with blue vitriol. After coloring, it may be clamped to the face of the die by means of the die clamp, and the outline of the punch marked on the face by scribing through the opening in the die. This outline should be accurately marked with a sharp-pointed prickpunch, as the scribed line is likely to become obliterated by the various operations of machining the punch to shape.

Milling or Planing. After the outline has been carefully prickpunched, the punch is ready to be milled or planed to shape, leaving enough stock at all points to shear into the die. If the punch is milled to shape, the irregular surfaces may be produced by means of a fly cutter, Fig. 333. If it is planed, it may be held in a pair of centers, as shown in Fig. 334, in a shaper. If the die has been left oft to permit laying off the punch, it should now be beveled for shear, and hardened.

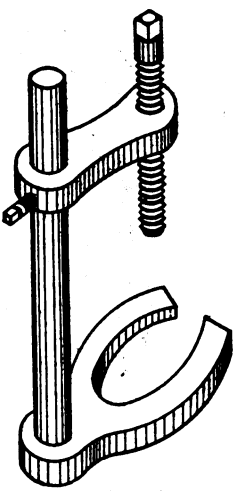


Fig. 332. Die Clamp

Shearing-In. The punch should be machined close to the lines, and then placed over the hardened die and forced into it a little, about $\frac{1}{16}$ inch. This is termed shearing-in, and is a customary process in this country.

Filing. After the punch has been sheared-in for a short distance, it may be removed and worked to size by means of chisel, file, and scraper to the witness mark, as the portion sheared-in is termed. The operation of shearing-in may be repeated until the punch enters the entire length.

Fit of Punch in Die. If the material to be punched is thin or soft, it is necessary to make the punch a closer fit in the die than if the stock is heavy or very stiff. Thin stock requires a punch nicely fitted to the die in order to avoid ragged edges on the punched blank. When punching brass stock $\frac{1}{8}$ inch in thickness, the punch

should be .0075 inch smaller than the die, the usual difference being 6 per cent of the thickness of the stock for brass, and 7 per cent for steel. If the stock is very stiff, a greater difference should be allowed, the exact amount depending on the nature of the material to be used and the character of the tool.

After the punch has been fitted to the die, the cutting end should be faced off to insure a good working surface and sharp edges. Any distinguishing names or marks necessary, should be stamped on it, after which it is ready for hardening.

Hardening. Punches are hardened by heating them in an oven furnace or in a clear charcoal fire, to a low red, and cooling

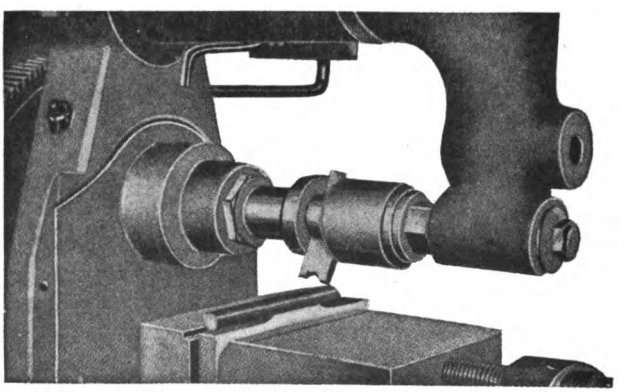


Fig. 333. Shaping the Punch with Fly Cutter

in water or brine, preferably the latter. Punches whose form insures strength, need be hardened only on the end; the hardening should not extend quite back to the shoulder or shank. Small, slender punches are sometimes hardened the entire length, especially if they are to punch stock nearly as thick as the diameter of the tool itself, for otherwise they would become upset when used.

It is generally considered good practice to have the punch softer than the die; on this account it is usually drawn to a color that insures this result. If a die is drawn to a straw color, the punch is drawn until it assumes a distinct purple, or even a blue color.

The punch is sometimes left soft—not hardened at all; when this is done, it can be upset, and refitted when worn. As this would

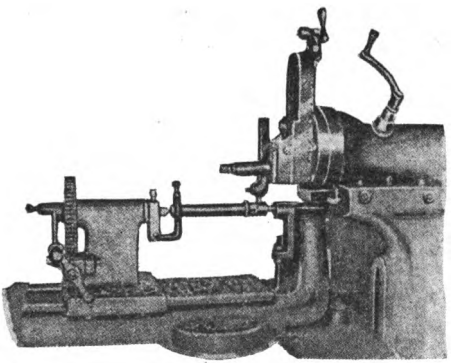


Fig. 334. Shaping Punch in a Shaper

not work satisfactorily in many cases, it can be recommended only when a soft punch is advisable.

Special Problems in Punching. *Punching Hole in Piece Machined to Shape.* It is occasionally necessary to punch a hole in a piece of work that has been machined to some given shape. The piece is placed on the face of the die against locating points, or in an opening in a gage plate, the opening being of the same outline as the piece of work. In Fig. 335 is shown a blank intended for a gunsight leaf; *A* shows the blank before the rectangular hole is punched, while *B* represents the leaf after punching. The hole is punched somewhat smaller than finished size, enough stock being left to work to size with broaches.

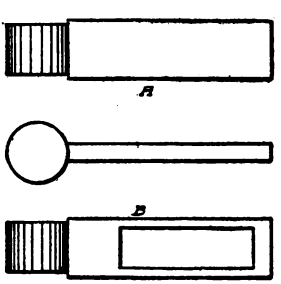


Fig. 335. Gunsight Leaf Punching

When punching work of this description, it is necessary to leave the face of the die flat; the punch is sheared as shown in Fig. 336. The piece punched from the leaf is of no value in this case; consequently, the face of the punch is

beveled, and the face of the die is left flat in order that the sight-leaf may be straight after punching.

Use of Stripper. When a die and punch are to be used for an operation similar to the one just described, it is necessary to make a stripper of a form that allows the pieces to be easily placed in position and removed. As the piece which is punched is likely to increase in width from the operation, it is advisable to have stops or a guide on one side only, in order that the piece be readily removed after the hole is made. Fig. 337 shows the die with stripper and guide attached. The stripper is raised sufficiently from the die to allow the work to be readily inserted. A gage pin is furnished for the end of the piece, to determine the position of the slot in relation to the end. On one side is a guide against which the piece rests to bring the slot into a central position, the piece being held by means of a screwdriver, a thin piece of steel, or a piece of wood.

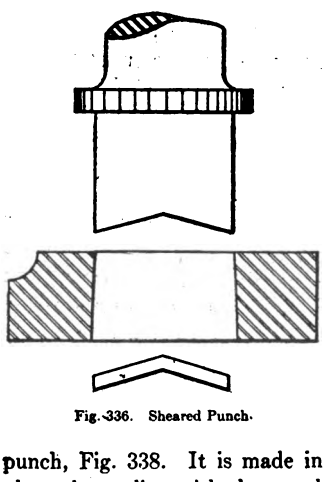


Fig. 336. Sheared Punch.

When the size of a piece to be punched does not allow the use of a stripper attached to the die, as in the previous example, the stripper may be attached to the punch, Fig. 338. It is made in such a manner that the stripper plate, descending with the punch, comes in contact with the piece being operated on and remains stationary; between the stripper plate and the punch holder are coil springs which are compressed. The punch passes through the piece and returns, and the stripper, being forced downward by the action of the springs, forces the blank from the punch. The gage plate which is securely fastened to the die by screws and dowel pins, as shown, has an opening of the same general outline as the blank, but somewhat larger, in order that the blank may be easily put in place and removed.

Punching Incomplete Holes. It is sometimes necessary to punch a hole incompletely, leaving the portion punched out attached at one

end, as shown in Fig. 339. If several holes are to be made in the piece, the punches may all be attached to one holder, and all let into one die block. This method of punching is resorted to when

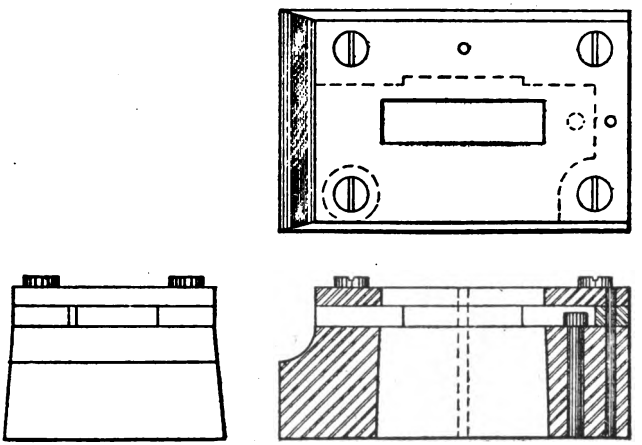


Fig. 337. Die with Stripper and Guide

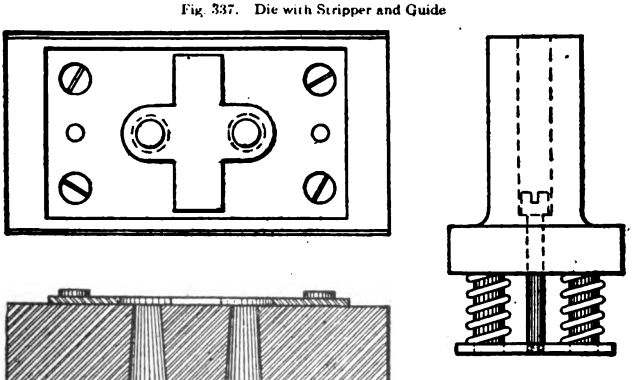


Fig. 338. Punch and Die with Stripper Attached

manufacturing skates, as the portion bent down from the plate is shaped by subsequent operations to provide a bearing for the toe clamps.

Piercing and Curling. A very satisfactory form of piercing and curling die is illustrated in Fig. 340. The various stages of the operation of punching, piercing, and curling are shown at *a*, *b*, and *c*. At *a* the punch is starting to pierce the sheet; *b* shows the punch having pierced the stock and starting to curl the loop; *c* shows the loop curled up against the sheet. If it is considered necessary, the punch may be set to go lower and curl the loop inside of itself, as shown at *d*; or the end of the punch may be flatted somewhat, as shown at *e*, and a loop formed as shown at *f*. This die may be made multiple, and any number of loops (within the capacity of the press) made and formed at one

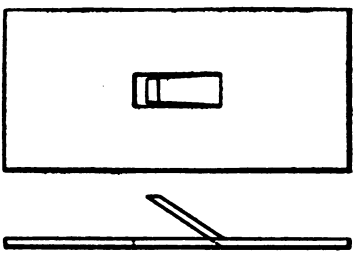


Fig. 339. Sheet Punched with Portion Removed Left Attached at One End

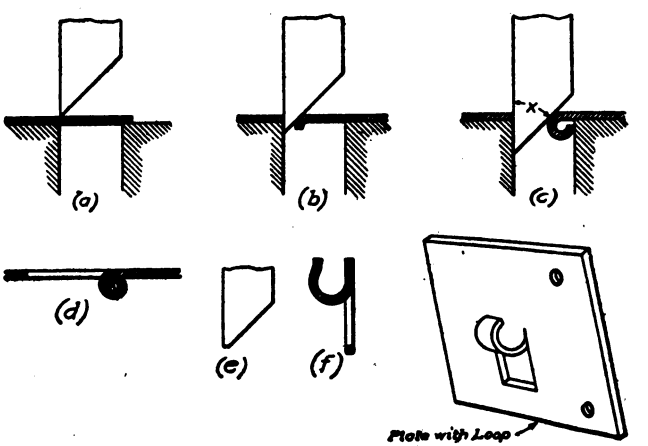


Fig. 340. Piercing and Curling Die

time; or piercing and cutting-off punches may be combined, screw holes or other holes punched, and strips of any desired length cut off, at one operation. A stripper plate, attached to either the

punch or the die, should be provided to strip the work from the punch. If attached to the die, the stripper must be high enough above the face to permit of easy removal of the work from the openings of the die.

Gang Dies. The gang die is designed to punch in one operation the blank itself and also any holes to be made in the blank. Two operations would be necessary if a punch and die of the form shown in Fig. 338 were used.

A common design of a gang die is shown in Fig. 341, which represents a die for the piece operated on in Fig. 338. The stock is fed from right to left. The sheet rests against the guide *C*, and is so located that the end slightly overlaps the first edge of the opening *E*. The two holes *F* and *F'* are punched, and the end of the sheet is trimmed by the punch *A* to furnish a locating point to go against the stop *D*. At each stroke of the press a blank is produced and the two holes are punched. For the next blank the gage pin *D* should be located about .010 inch farther to the left than the proper location for punching. The center pins, as they enter the holes, draw the stock back to the proper location. It is obvious that the punch *A* must be a trifle longer than the punches *B'* and *B;* were the small punches longer

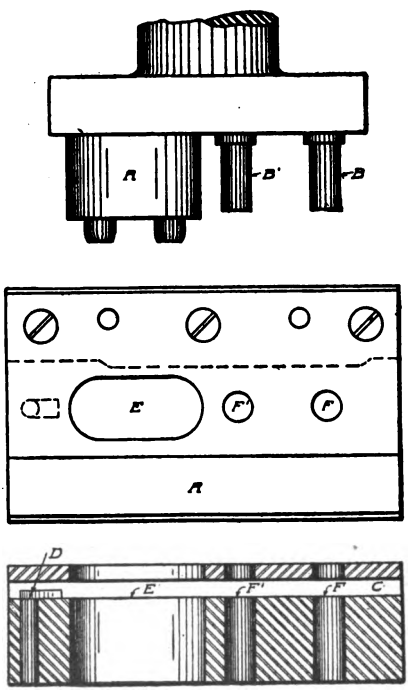


Fig. 341. Gang Die

than *A* or even of the same length, they would hold the stock in such a manner that the centering pins could not locate it, and, moreover, the centering pins, striking on one edge of the hole, would spoil the blank punched, and probably cause the pins to break. The centering pins must not be a tight fit in the holes, or the punched blank will stick to the pins and return with the punch. By carefully fitting the pins to a punched hole, punching

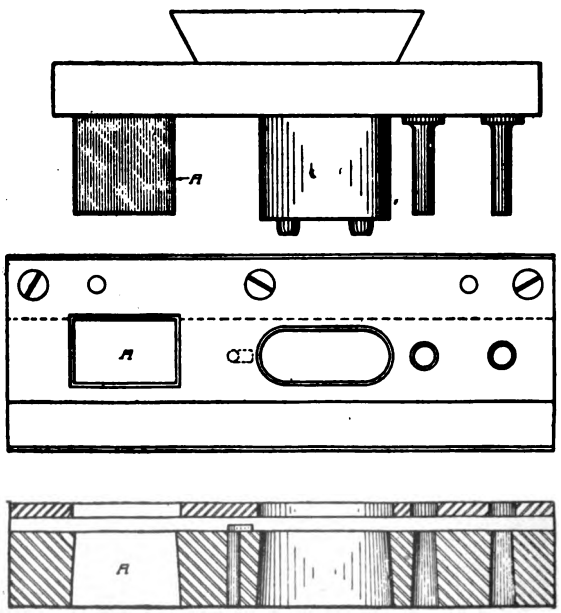


Fig. 342. Punch and Die Which Cut Away Scrap

within a very small limit of variation can be insured; in fact, for most classes of work, it is possible to punch near enough to standards for all practical purposes.

When a gang die of the design shown in Fig. 341 is used to punch a strip wider than is necessary to get out two punchings, it will be readily seen that the scrap left between must be removed by some means. This is frequently done by a large lever shear

or a pair of power shears, but that is a costly operation where many pieces are punched at a time. To avoid this extra cost, dies are made with an extra opening, and a punch working into this cuts away the surplus stock or scrap, leaving the edge of the sheet straight and in condition to rest against the guide. In Fig. 342, the opening *A* is the trimming die; the punch working in this cuts away the scrap, leaving the edge of the sheet straight.

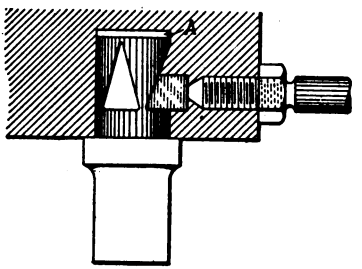


Fig. 343. Punch Holder to Prevent Loosening

At times, punches set in a holder, Figs. 341 and 342 have a tendency to loosen and draw out of the bearing. A method for preventing this is shown in Fig. 343, an angled block pressing against the punch shank A.

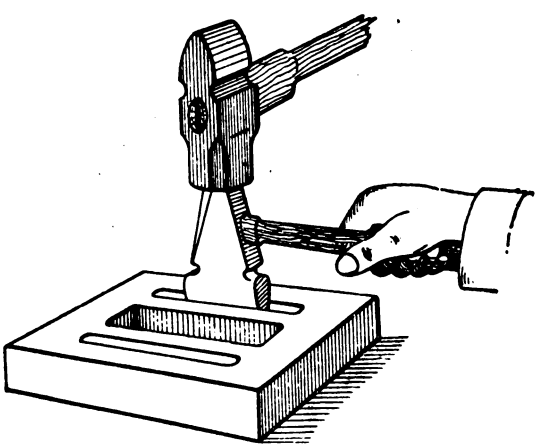


Fig. 344. Repairing Worn-Out Die with Fuller

When a die becomes worn through use so that the opening is large, it may be placed in the fire, brought to a forging heat, and the opening closed with a "fuller", Fig. 344. After being annealed,

the die can be worked out to size and hardened. In this way dies can be worked over several times. Fig. 345 shows a die with the core sawed out by means of a power saw, Fig. 218.

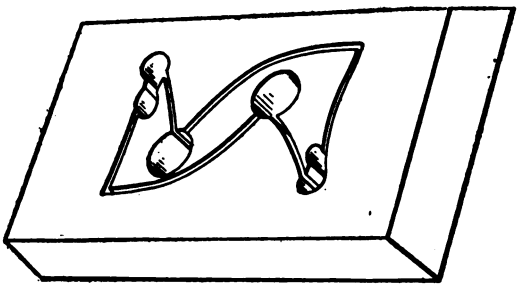


Fig. 345. Die with Core Sawed Out

Punches with Guide Bushings. A great amount of trouble is experienced in some shops when attempting to use small piercing punches to produce holes in stock as thick as the diameter of the

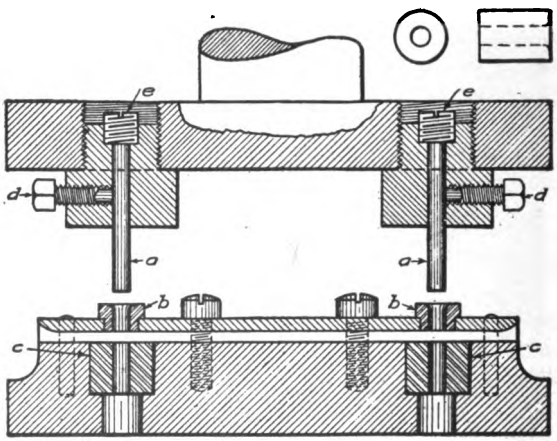


Fig. 346. Die with Guide Bushings

punch, or thicker. This difficulty can be obviated by using guide bushings in the stripper plate to support the punches and guide them to the opening in the die. The bushings should be made

from tool steel, hardened, the holes ground and lapped to an exact fit for the punches; or, in the case of very small punches, where grinding is out of the question, the hole may be lapped to size, and the outside ground to size to force it into the hole in the stripper plate.

The guide bushings must be in exact alignment with the openings in the die. Fig. 346 shows a form of die provided with guide bushings *bb*, for the punches *aa*. The dies *cc* are made from tool steel, hardened, and forced into a machine-steel die block. The punches are made from drill rod and are held in place by binding screws *dd* and adjusting butt screws *ee*. Between the binding screws *d* and the punch, at the end that bears against the punch, is a piece of wire of semicircular shape. This allows the punch to be set down as the punching end is ground away.

In the case of gang punches and dies, used in the production of perforated sheet-metal work, which have sometimes several hundred piercing punches working into one die, it is customary to provide each punch with a guide bushing.

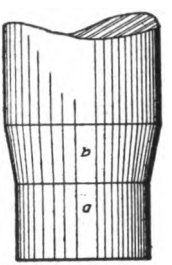


Fig. 347. Punch Designed for Clinging Metal

Punches with Tapered Section for Spreading. Trouble is experienced at times with blanking and piercing punches because the metal clings to the punch and pulls the end off in the operation of stripping. This is especially the case when a clinging metal is being worked. The trouble can be avoided by making the punch of the design shown in Fig. 347, where the portion marked *a* is straight and the desired fit in the die. The portion *b* is tapered and smaller at its junction with *a*. When the die is set up in the press, *a* enters the die nearly its entire length; the tapered portion *b*, entering the stock, spreads it, thus enlarging the opening, and so preventing it from binding the punch during the process of stripping. It is of course necessary, when setting a punch of this design in the press, to make sure that the tapered portion does not enter the opening in the die.

Multiple Die. If the shape of the pieces to be punched allows it, it is sometimes advisable to make several openings in the die of the same outline so arranged that as many pieces may be punched at a time as there are openings in the die block. This will effect

a great saving where work is punched in large quantities. In the manufacture of perforated sheet-metal work, it is customary to make dies having as many as five hundred punches working into one die block at a time; but as this is an unusual application of this principle, it will not be considered.

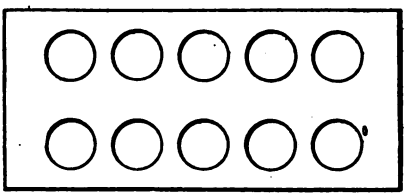


Fig. 348. Sheet-Metal Blank

If it is necessary to punch ten holes in the piece shown in Fig. 348, a die can be made having this number of openings. Then, by making a punch holder having an equal number of punches properly located, all the holes can be punched at one stroke of the press.

While in the case just cited the piece of stock which had the holes punched in it is the product, the punchings being scrap, the same principle can be applied to punching blanks from a sheet of stock. The design shown in Fig. 349 is the product in a shop where many thousands of this piece are used monthly. The die produces a dozen or more blanks at each stroke of the press, but for convenience in illustrating the die and punches, but four openings in the die, with a corresponding number of punches are shown, Fig. 350.

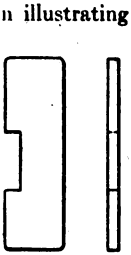


Fig. 349. Simple Stamping Twelve Produced at a Stroke

If a die were made with the openings near enough together to punch the stock, Fig. 351, there would be so little stock between the openings that the die would not stand up when used; for this reason the openings are located in such a manner that every other opening is omitted. When the punch descends, four blanks are punched, and, the stock is moved until the first opening strikes the gage pin, Fig. 350. This leaves the stock in position to punch between the openings already made. The next time the stock is moved until the gage pin strikes the wall of the last opening to the right.

Bending Die. In order to bend metals to various forms, dies are made for use in punching presses, drop hammers, and various

other machines. A simple form of bending die is shown in Fig. 352. The shape of the upper and lower parts of the die is such that when the upper part is brought down on the blank *B* (shown by the dotted

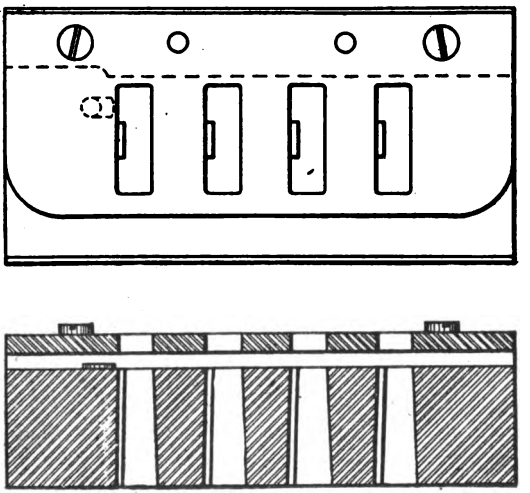


Fig. 350. Gang Punch and Die for Simple Punching

lines) that will be bent to the required shape. The shoulder *A* forms a locating stop, against which the blank rests before bending.

Dies for extremely soft metals may be made of the exact shape of the model, or the shape the piece should be when finished; but if the piece is of stiff material which bends with difficulty, it will be necessary to make the die of a form that will give the article *more* bend than is required, as the piece will spring back somewhat as soon as released by the return of the upper part.

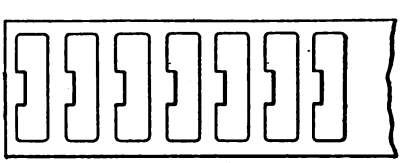


Fig. 351. Punchings Too Close Together

The bending of articles of certain shapes requires tools so designed that certain portions of the piece will bend before others. Any attempt to make the tools solid, and thus to do the bending

of the various portions at once, would result in stretching the stock As a rule it is not advisable to stretch stock, and dies are constructed to do away with this trouble.

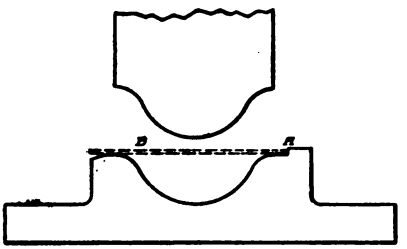


Fig. 352. Simple Bending Die

Bending Die for Right Angles. Under certain conditions a bending die which has a horizontal surface for the work to rest on and a vertical-sided punch does not work in a satisfactory manner—this is especially true when the stock is stiff. In that case, a die of the design shown in Fig. 353 works well, as the angle may be made other than 90 degrees to allow for the spring of the metal.

This design of die may be used for angles other than right angles. It is especially satisfactory for bending springs and other pieces made from a stiff stock that is liable to spring back somewhat after bending, as the lower block may be made with an angle greater than 90 degrees to allow for this factor.

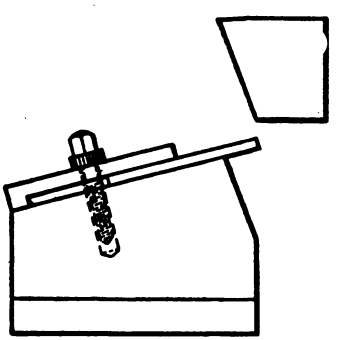


Fig. 353. Bending Die for Right Angles

Bending Die for Light Work. For comparatively light work, the form of bending die shown in Fig. 354 is very satisfactory, and may be used for a variety of shapes and angles. The die block *a* is drilled and reamed to receive the shouldered portion *b*. The rectangular groove, to receive the pad, is milled or planed, and the pad is fitted and forced in. The proper angle or shape is then milled in the block *a* and pad *b*. The surfaces are carefully finished and the pad forced out and drawfiled until it slides nicely in the groove. The spring *c* forces the pad against the washer *d*. Gage plates are provided to locate accurately the pieces to be bent.

Fig. 355 shows a die, the upper part of which has the portion *a* so constructed that it engages the stock first and forces it down into the impression in the lower portion. The resistance of the coil spring is then overcome, and *a* is forced up into the opening provided for it. The arms *cc* bend the ends of the piece. After bending, the article is of the form shown at *b*.

Compound Bending Die. In Fig. 356 is shown a form of die used in bending bow spring and looped wire for armature connections or other looped wire-work. The work is placed in the die, and the punch, as it descends, bends the wire to the shape of the die. The spring just back of the punch is compressed; this allows the punch holder to descend and force the side benders *BB* toward the punch by means of the wedge pins *AA*, and thus forms the piece into a circle. Fig. 357 shows the punch when down. It is obvious that it is necessary to make the shape of the punch and die different. The lower die must have its bending surface a curve of a radius equal to the racius of the punch plus the thickness of the material.

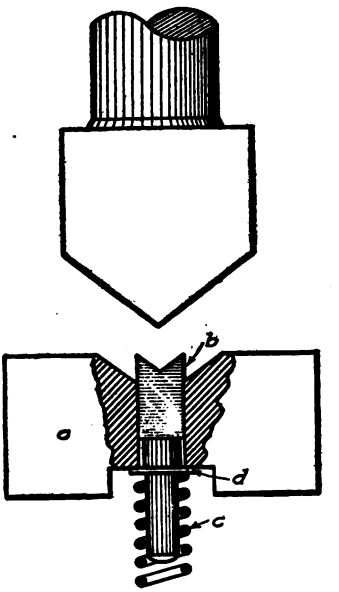


Fig. 354. Bending Die for Light Work.

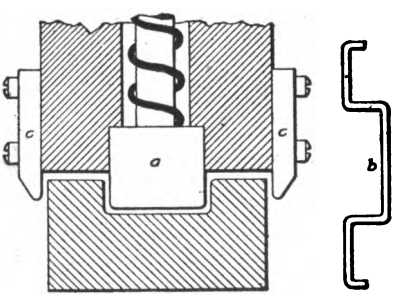


Fig. 355 Spring Bending Die and Finished Piece

Forming Die. This type of die is familiarly known as a *drawing die.* The most common example of the forming die is that used for

drawing a flat, circular blank, shown at *A*, Fig. 358, into a cup-shaped piece, shown at *B*. This operation can be done in an ordinary

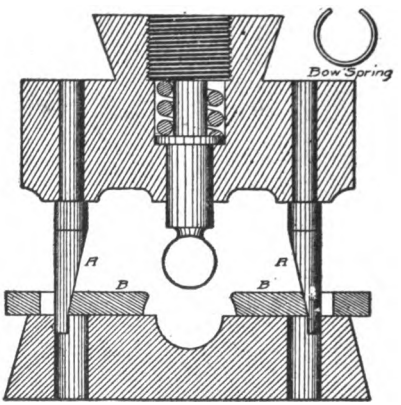


Fig. 356. Compound Bending Die

punching press by means of a forming die of the shape known as a *push-through die*, so called from the fact that the piece is formed to shape and pushed through the die at one operation. This form of die is shown in Fig. 359. The face of the die is cut to receive the blank; this depression is known as the "set edge". The opening

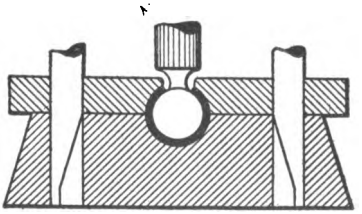


Fig. 357. Punch at Bottom

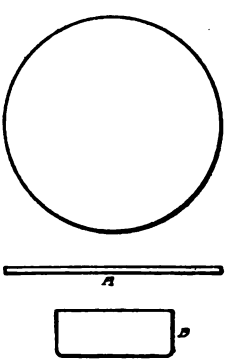


Fig. 358. Flat Blank Drawn into Cup Shape

in the die is given a "draw" of from $\frac{1}{4}$ to $\frac{1}{2}$ of a degree, making it larger at the top; the upper edge is rounded over and left very

smooth, and the bottom edge is made very sharp, in order that the piece may not be carried back with the punch as it returns.

This form of die is left as hard as possible, and the walls of the opening are made as smooth as they can be polished. It is sometimes advisable to finish the walls with a lateral rather than a circular finish.

Hardening Drawing and Redrawing Dies. Drawing and redrawing dies having holes which pass entirely through them, as shown in Fig. 360, give considerable trouble when hardened unless proper methods of treatment are used. The principal difficulties experienced are alteration in the size of the hole, and soft spots in the walls of the holes.

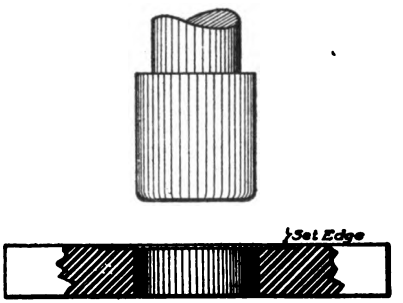


Fig. 359. Push-Through Die for Cup-Shaped Work

As there is no need for the exterior of the die being hard, the whole attention of the hardener should be given to getting the walls of the hole as hard as possible, as this portion is subjected to considerable strain and to excessive abrasive action, and soft portions render the die useless. This is especially true of dies used for such work as redrawing cartridge shells and similar pieces.

In order to harden the walls of the hole, and yet leave the circumference of the die soft, it is necessary to make a fixture to cover the portions desired soft. Such a fixture is shown in Fig. 360. It may be made from a piece of cast iron, the portion *A* being a little, say 1 inch larger than the diameter of the die. The opening to receive the die should be $\frac{1}{16}$ inch larger than the die. The balance of the hole should be somewhat larger than the hole in the die, say $\frac{1}{4}$ inch. A cover may be made of the same material, and it should be a loose fit on the holder. The hole in the cover should be $\frac{1}{4}$ inch or more larger than the hole in the die and beveled as shown.

When the die is heated to a uniform red, it is placed in the fixture, the cover put on, and the whole held under a water pipe, or faucet, Fig. 362, while the water is allowed to flow through the

hole as shown. A mistake sometimes made consists in placing the fixture in a bath and then attempting to force the water through the hole; unsatisfactory results always follow if this is done, for the water cannot flow through the hole, pockets of steam form which prevent hardening, and soft spots result. The fixture should *not* be immersed in water, but should be held so that the water can pass unretarded through the hole and carry the steam with it. The water supply should be sufficient to fill the hole and should pass through under a fair head, but not too swiftly. This method, when properly executed, gives excellent results. As a rule, dies of this kind are left dead hard, the temper not being drawn at all.

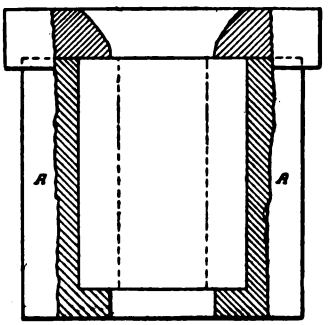


Fig. 360. Fixture for Covering Soft Portion of Die

Reversed Die. The die shown in Fig. 362, known as a reversed die, is extensively used in many shops for heavy punching on such work as washers, ball seats, etc. Under many conditions, it works much better than a gang die, and it is simpler to make than a compound die.

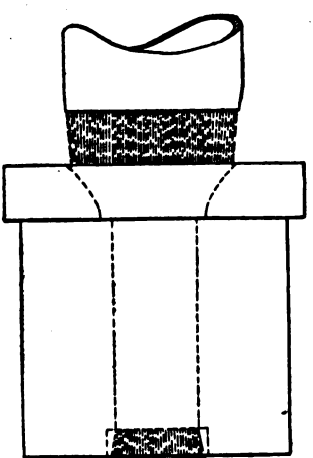


Fig. 361 Method of Hardening a Redrawing Die

The punch *A* is made the size of the diameter of the washer to be produced, and is hollow to receive the punch *B* which produces the hole. The scrap from *B* passes up through the punch *A* and through the outlet shown. The washer blank remains in the die *C* until forced out by the ejector *D*, which is automatically operated by the press.

Compound Dies. In Fig. 363 is shown a die used in producing a washer and punching a hole in it at one operation, thus insuring a blank with a hole that is exactly central. The work from a die of this description is better than that done by the gang die. It is especially adapted for thin sheet metal, paper, and mica parts.

The upper die *A* receives the lower punch *B*, while the lower opening *C* receives the upper punch *D*. The stripper *E* forces the

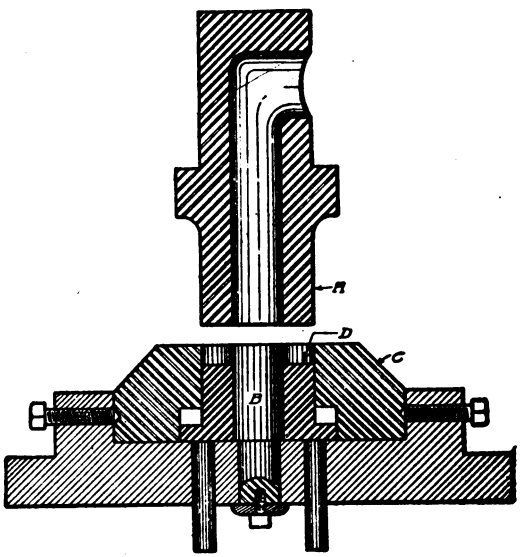


Fig. 362. Reversed Die

blank out of the die; while the stripper *F* forces the sheet off the punch *B*.

The die shown is for punching a round washer, but the tool may be made for producing pieces of complicated and irregular form. It proves especially valuable when used in connection with a sub-press.

Triple Dies. When it is necessary to punch three or more holes in a tubular or other shaped piece where this form of die can be used, a triple die effects a great saving, as the holes can be punched at one stroke of the press.

Fig. 364 shows a die used for punching three holes in a tube and is intended for use in any simple power press. The dies *AAA* are placed in a hollow stud which fits in the inside of the piece to be punched. The vertical punch is held in the punch holder as shown. The horizontal punches are operated by means of the inclined arms *CC*, working in the horizontal slides *BB*.

The horizontal punches in the illustration are made from drill rod of the desired size; but they may be of any desired form,

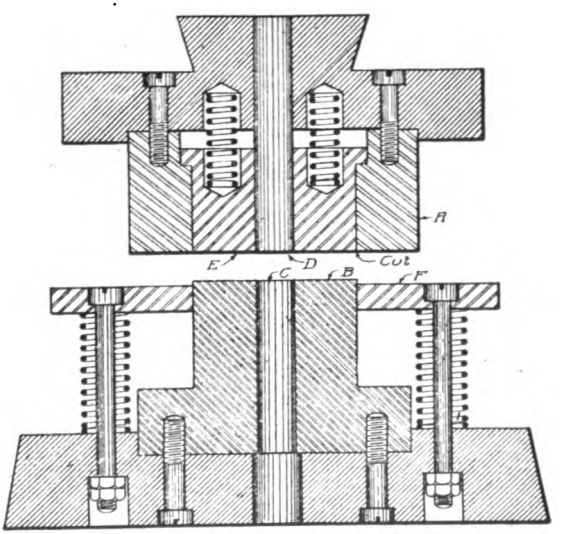


Fig. 363. Compound Die for Producing Washer at One Operation

the opening in the die being made to match. Where work is done in batches sufficiently large to warrant the expense of a triple die, its construction is to be recommended, as better results can be obtained than if one hole is punched at a time.

Follow Dies. The name follow die is given that form of die where the pieces are blanked and bent at one operation. In Fig. 365 is shown a punch and die used in producing the piece shown at the left. The two holes in one end and the opening at the opposite end are punched, and the piece bent to shape, at one passage through

the press. The bending, piercing, and cutting-off punches are all attached to the same holder as shown in the upper part of the cut.

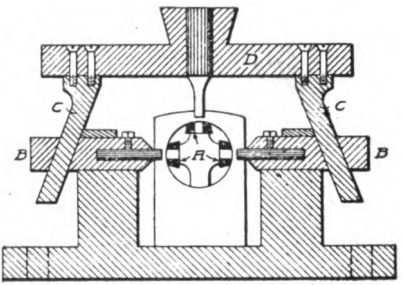


Fig. 364. Compound Die for Punching Three Holes in a Tube

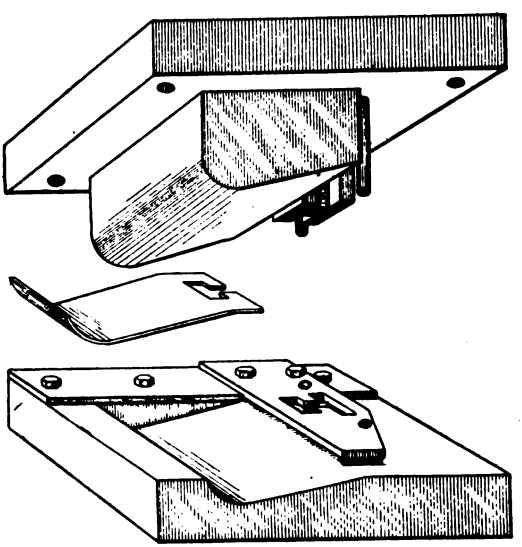


Fig. 365. Follow Die and Piece Produced

If the stock to be punched is soft, the bending portion of the punch and die may be made nearly the shape of the desired piece; if, on the contrary, the stock is stiff, they must be made of greater

angle to allow the piece to spring back after punching. The amount to be allowed cannot be stated, but must be determined by experiment. This test may be made while the die is soft, at which time the piercing or cutting-off portions must not be used. Dies of the type under consideration give best results if hardened by pack hardening.

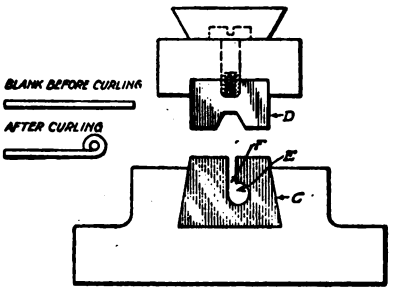


Fig. 366. Curling Die and Work. Before and after Operation

Curling Dies. These dies are used in forming a loop such as is shown in Fig. 366 and marked "After Curling". The loops on hinges and similar pieces are examples of its work. The stock is first punched out as shown at the upper left-hand corner. and the blanks are forced into a curling die of the design shown at *C*. The punch *D* has a V-shaped impression in its face, as shown.

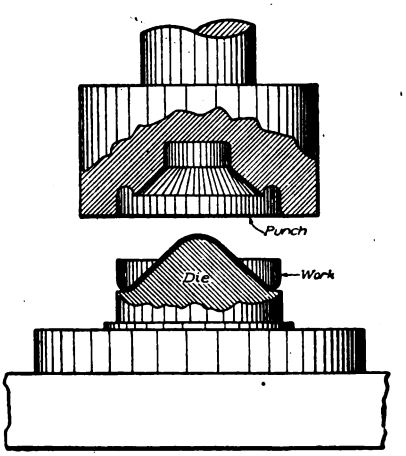


Fig. 367. Another Form of Curling Die

In making this die, the block *C* is machined to size. The hole *E* is drilled, reamed, and lapped to size; the lapping also produces a smooth hole, if a round, revolving lap of the right size is used. The slot *F* is then milled.

If the stock is comparatively soft or is easily bent, and if the die is to be used for but a few holes, it need not be hardened; if intended as permanent equipment, it must be hardened, preferably by the pack-hardening process.

Another form of curling die, Fig. 367, is used in curling a loop around the end of a circular shell or vessel. The stock entering the circular-shaped portion of the punch is made to conform to the size of the circle.

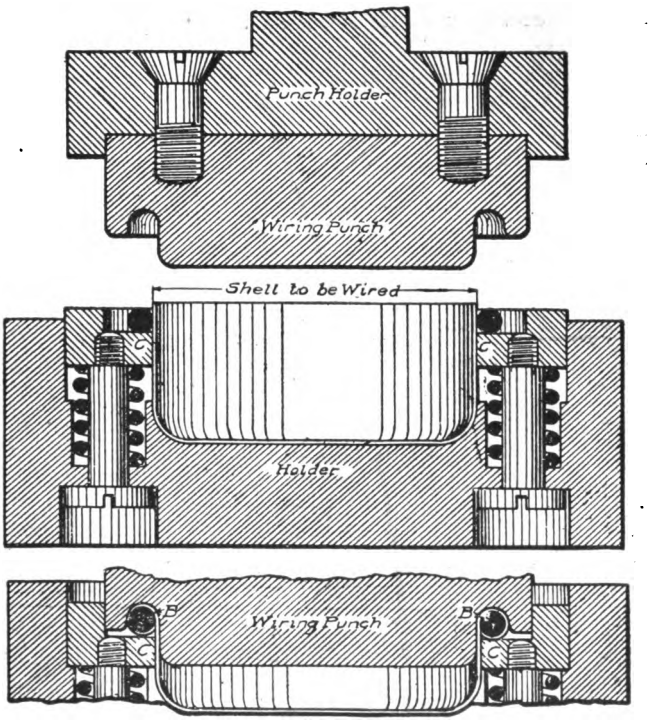


Fig. 368. Wiring Die

Wiring Dies. Wiring dies are similar in construction to curling dies. They are used to curl the upper edge of a vessel which is in the die, or holder, and lies on the top of a spring-supported ring *C*, Fig. 368.

As the punch descends, it depresses the ring *C* and curls the upper edge of the vessel around the wire ring, as shown at *B*.

Compound Punching and Bending Dies. In Fig. 369 are shown three views of a punch and die for cutting off and bending to shape at one operation a piece of special form; *D* is the finished piece. This form of die can be used for a variety of work, and it is recommended wherever the work is done in sufficient quantities to warrant the expense of the tool.

A is a view of both punch and die, showing also the punch holder and bolster; *B* shows the stripper used in knocking the finished piece from the bending punch; the cutting-off portion is seen in side elevation. The stock is fed through, and strikes the stop.

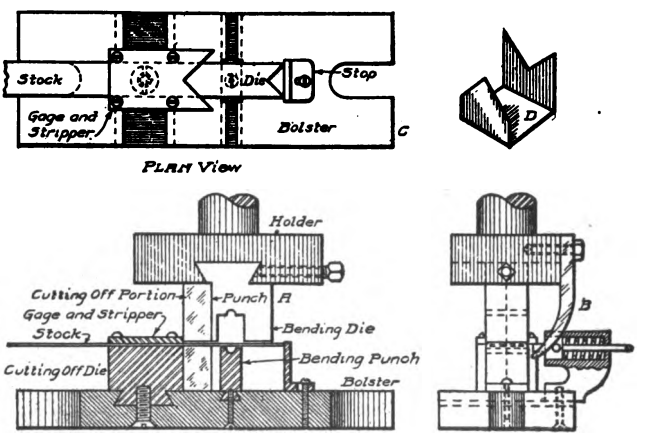


Fig. 369. Compound Punching and Bending Die

The cut-off is slightly longer than the arm of the bending die, in order that the stock may be cut off before the bender reaches it.

The stripper is a horizontal plunger actuated by a coil spring. This plunger has a pin through the back end to prevent it going too far, while another pin extends through the enlarged portion, against which the spring works. The inclined arm fastened to the punch holder will, when descending, force the plunger back and off the face of the bending punch. *C* is a top view of die.

There is sufficient space between the upper surface of the cutting-off die and the stripper so that the stock can pass over the plunger

stripper. The inclined arm which operates the plunger stripper pushes this out of the way before the descending punch reaches the stock.

After hardening, the cutting-off die and punch are drawn to a full straw color, and the bending part to a brown. When the cutting and bending parts are of complicated design, best results follow if they are pack hardened. The stock is purchased with the desired width, and the pieces punched and bent with no waste of stock.

Progressive Dies. Fig. 370 shows a die used to bend a caliper bow to a finished circle. This type of die may be used to produce pieces that are square in form, or of any one of a variety of shapes. It is generally necessary to resort to one or more preliminary bending

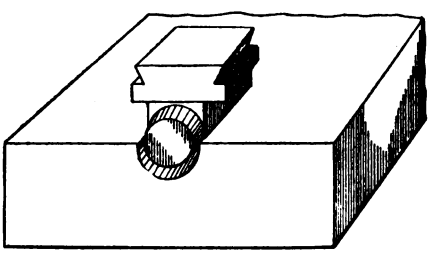


Fig. 370. Progressive Die for Bending Caliper Bows

operations to get the pieces to a form that makes it possible to bend them to finish form in the die shown. Since one or more dies are used before the final finishing die, and since one operation leads to another, dies of this class are grouped under the head of progressive dies.

The bow *a*, Fig. 371, is made by first punching a blank of the form shown at *b*. The ends of this blank are then bent separately, and shown at *c* and *d*. The piece is finally bent to the shape *a* by means of the die under consideration. It will be noticed that the forming portion of the punch projects out from the body and is provided with clearance space above it, in order that the ends of the piece may bend around it, and against one another if necessary. While the example of work given is simple, yet pieces of intricate shape can be produced by means of dies of this kind.

Another example of progressive dies and the work done with them is shown in Figs. 372 to 378, where Fig. 372 shows the die

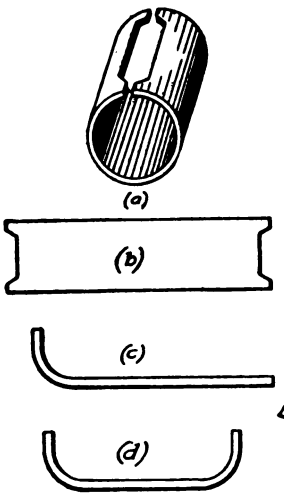


Fig. 371. Various Punchings in Making a Caliper Bow

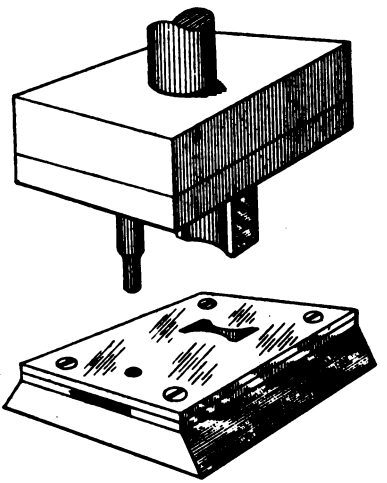


Fig. 372. Punch and Die for Making Special Copper Strips

used in piercing the hole, in forming and cutting off the ends, and producing a blank of the form shown in Fig. 373. The stock used

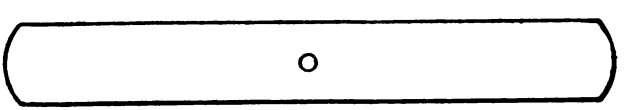


Fig. 373. Copper Strip after the Second Stage

Fig. 374. Copper Strip after Third Stage

is ribbon copper of the desired width of piece; this is purchased in coils and fed to the die shown in Fig. 372, by an automatic feeding device.

The pieces are next bent to form, Fig. 374, by means of the bending die and punch, Fig. 375. The third operation is done by means

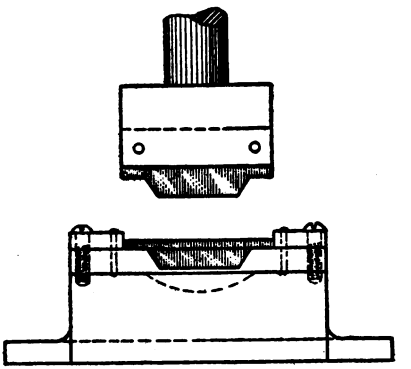


Fig. 375. Punch and Die for Bending Copper Strip at Third Stage

of the punch, Fig. 376, and the die, Fig. 377. The punch *A*, Fig. 376, folds the piece shown in Fig. 374 around the projecting portion and forms it to the shape shown in Fig. 378

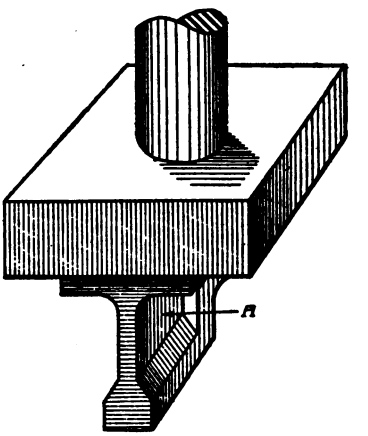


Fig. 376. Punch for Bending Copper Strip at Fourth Stage

Although it might be possible to bend a piece of this description in a compound bending die at one operation, it is doubtful if the ultimate cost would be any less than that of the individual operations, as the cost of upkeep would be much greater, and the process somewhat slower. There are many jobs where it is advisable to use compound bending dies; but where there is no saving in cost of labor, or where the presses are not adapted to their use, it is best to resort

to methods particularly suited to the individual job, even though it necessitates a greater number of operations.

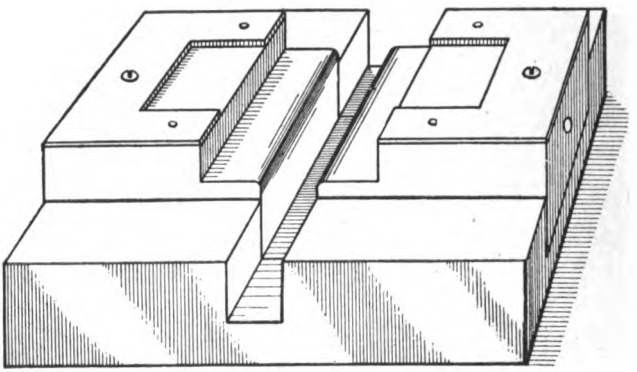


Fig. 377. Die for Bending Copper Strip at Fourth Stage

Sub-Press Dies. A sub-press is a small self-contained press which is operated by a large press. It is extensively used in watch and clock shops for punching the movements. Fig. 379 shows samples of work done on this press. Figs. 380 and 381 show different styles of sub-presses.

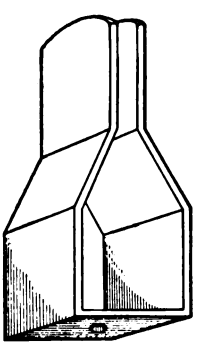


Fig. 378. Final Shape of Copper Strip

While sub-presses differ in design, the pattern illustrated in Fig. 382 is well adapted for general use. The upper portion *A* of the press, as shown in cross-section, is bored out tapering to receive the Babbitt sleeve, and the feet are bored to fit on the base. A thread is cut at the top to receive the nut used in holding the Babbitt lining tightly in place. The die goes in the base, and is made in the usual manner. The punch, which is held in the plunger *B*, is carefully set, and the space around the plunger is filled with Babbitt metal, poured in the usual manner. In order that the plunger shall be held from turning, three or four parallel grooves are

milled as shown, before the Babbitt metal is poured, the latter, filling the grooves, acts as a guide.

The slot at the top of the plunger engages loosely in the gate of the press, so that absolute accuracy in the working of the ram of the

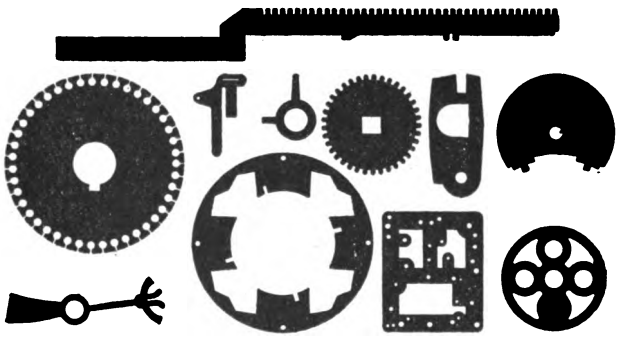


Fig. 379. Work Performed by Sub-Press

press is not essential. A good press, however, is always to be preferred. It is considered good practice to adjust the press so that the punch does not actually enter the die, but comes just far enough

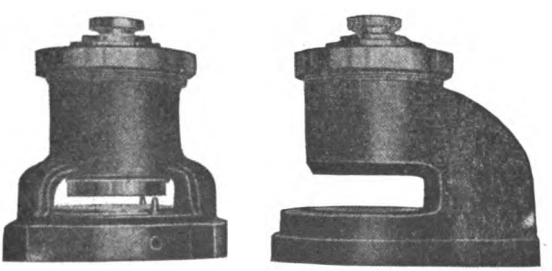


Fig. 380. Two Forms of Sub-Press

to punch the blank out of the stock without the edges of the die and punch coming in contact.

The sub-press is especially valuable for complicated dies, and many compound dies are used in this form. Complicated dies, which, when made in the ordinary way, would produce but a com-

paratively few pieces, will, when sub-pressed, punch from 20,000 to 50,000 pieces.

Use of High-Speed Steel for Dies. The advisability of using high-speed steel for punch-press blanking, bending, forming, and other dies, depends in a large measure on the facilities in the individual shop, for hardening tools made from this steel. If conditions are favorable, there is no doubt that many dies made from high-speed steel will produce several times the amount of work which the same die made from carbon steel will produce. This is especially

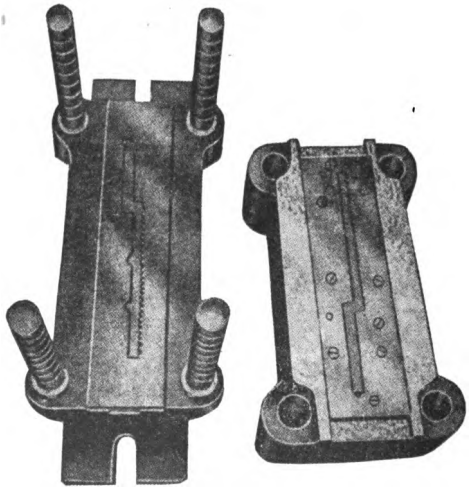


Fig. 381. View of Dies of Sub-Press

true of forming, bending, and drawing dies, where there is crushing strain and a tendency to wear from abrasion.

In making a die, as in making many other forms of tools, the principal item of expense is the labor; the difference in the cost of steel is insignificant when the life of the tool and the increased amount of work it will turn out are considered.

Dies made from high-speed steel should be pre-heated to a low red in some form of pre-heating furnace; then placed in a high-speed furnace and raised to a uniform temperature of from 1750° F. to

2100° F., after which they should be removed and immediately plunged into a bath of oil. Dies that are not to be subjected to great strain or extreme shock may be heated to the higher temperature mentioned, while those that are to be subjected to strains should receive lower heats. Different makes of steel require different temperatures on account of the varying percentages of alloys. As a result, exact temperatures cannot be definitely stated.

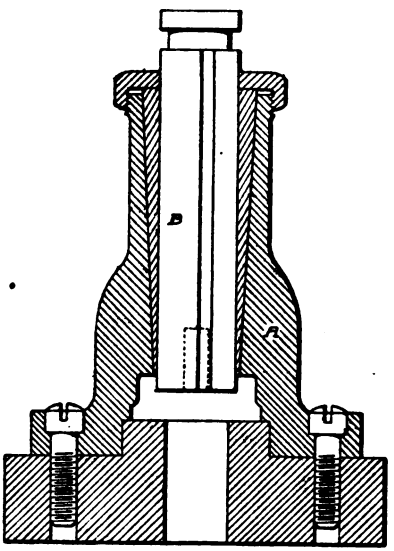


Fig 382. A Pattern of Sub-Press

After hardening, the temper should be drawn from 460° F. to 530° F., depending on the strain the tool is to receive. If the strains are excessive, the higher temperature must be given.

Fluid Dies. These are used in the production of various kinds of hollow ware, such as vases, lamp bodies, match safes, etc. The metal may be Britannia ware, silver, or soft brass. The die is generally a casting of soft close-grained iron. It is made in several parts, as it is necessary to open it in order to get the piece out.

Fig. 383 shows a die of this description. The plunger works down through the knurled sleeve, thus causing the confined fluid,

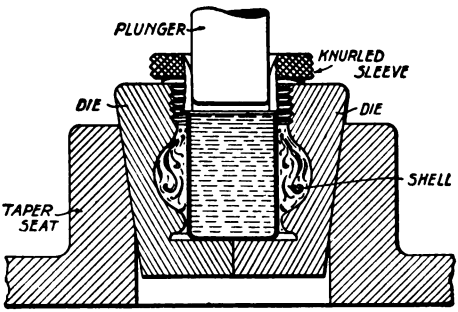


Fig. 383. Fluid Die Showing Plunger and Mold

with which the piece has been filled, to force the metal out into the impressions in the mold.

It is the custom in some factories to use soft rubber in place of the water or other fluid, the plunger pressing on it and thus swelling the metal out into the die. It is claimed that in producing clear-cut outlines and full, sharp corners, the rubber works better than a fluid.

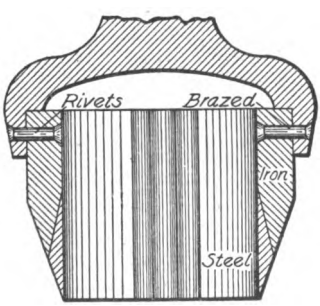


Fig. 384. Hollow Punch of Tool Steel Welded to Back of Norway Iron

Hollow Punches. When work is to be punched from paper, cloth, or leather, hollow cutters or *dinking dies* are commonly used. They give better satisfaction and are more cheaply produced than the ordinary punch and die used for blanking. Several thicknesses of material may be cut at once, the punch may be driven through the material with a maul or mallet operated by hand, or it may be used in a press.

While the cutter may be of ordinary tool steel, it is customary to use stock made especially for the purpose, by welding a suitable

grade of tool steel to a back of Norway iron, as shown in Fig. 383, where the metal is represented in cross-section.

In some shops, the strips of iron and steel are welded as required. As a rule, however, better results are obtained if the commercial article is purchased, for the welding is done at the steel mill under conditions which insure better material and more solid joints.

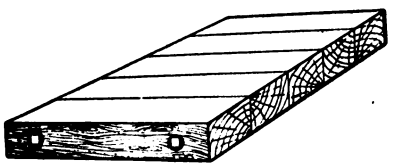


Fig. 385. Cutting Board to Be Attached on Base of Press

From a templet made for the shape of the desired opening in the cutter, the blacksmith forms the tool, and welds it. The cutting edge is beveled on the outside, as shown in Fig. 384, to an angle of about 20 degrees. After welding and shaping, the inside is filed to the desired size and shape, allowance being made for the shrinkage which takes place when the cutter is hardened.

This form of cutter can be used in a hand, foot, or power press; or it can be used by hand. If designed for a press, it is made without a handle, the cutter being brazed to a base; the brazing material is soft brass, borax being used for the flux. In some instances the cutter back is bolted to the press base, the cutting edge uppermost; in other cases, the base is attached to the movable ram of the press, and the stock to be cut is placed on a board on the base of the press. This board is made by gluing together several pieces of hard, well-seasoned maple, the pieces being arranged as shown in Fig. 385, so that the end grain of the wood forms the surfaces on which the cutter strikes. The various blocks should be securely held together by bolts in addition to the glue. After gluing and bolting, the surfaces should be worked down flat, smooth, and parallel. When not in use, the board should be dampened slightly to prevent the opening of the grain of the wood.

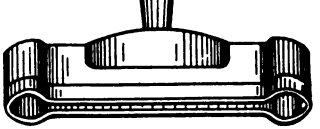


Fig. 386. Cutting Die and Handle

If the cutter is to be operated by hand, a handle such as shown in Fig. 386 should be provided. This handle is brazed to the cutter,

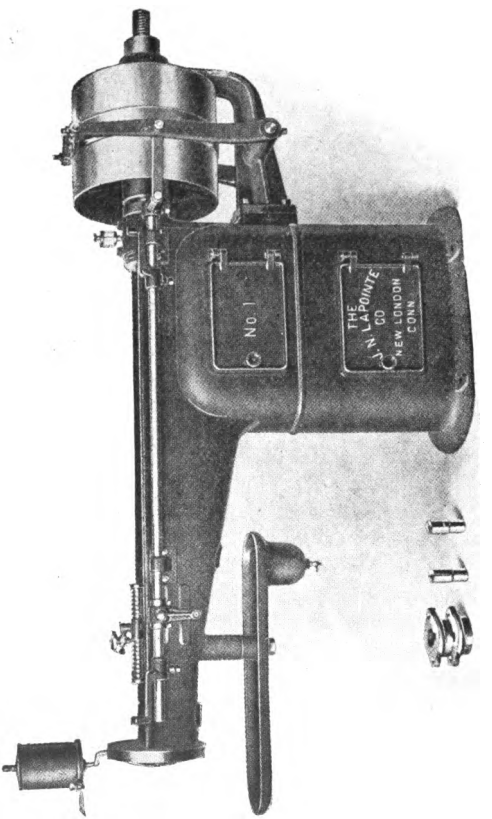


Fig. 387. Draw-Broaching Machine
Courtesy of J. N. Lapointe Company, New London, Connecticut

usually before hardening the tool. In many shops this form of tool is called a *cutting die.*

BROACHES

The operation of broaching is many times classed under the same head as that of punching with punches and dies, as both may be done in the punch press, and when such is the case, the operations resemble each other.

Formerly all broaching was done by pushing the cutting tool—broach—through the stock. At the present time, a form of machine

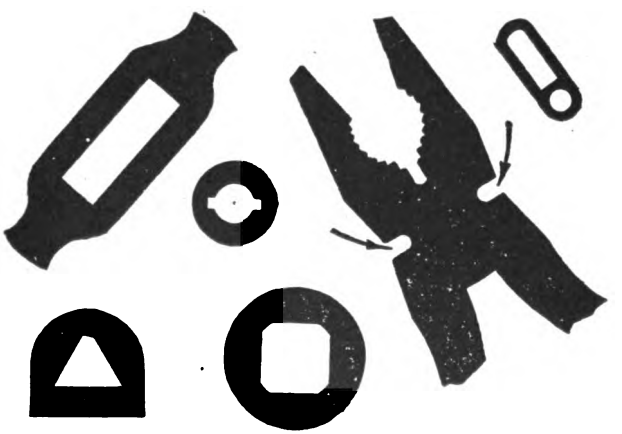


Fig. 388. Samples of Work

called a draw-broaching machine is used in many shops, and the tools are drawn through the work. It is possible, with the draw broach, to make the broaches much longer than in push broaching, so that one broach of the former kind may be made to do as much work as several of the latter. In actual practice, one draw broach has accomplished as much work as twelve push broaches, and in less than one-fifth of the time, thus effecting a decided saving in time and cost of tools.

The process of draw broaching has revolutionized certain methods of manufacture, especially that of producing straight holes of irregular form running quite through pieces of work. While

broaching by means of push-through broaches has been practiced for many years, draw broaching is of comparatively recent origin. The success of the method depends in a great measure on the design and construction of the broach used in producing the hole.

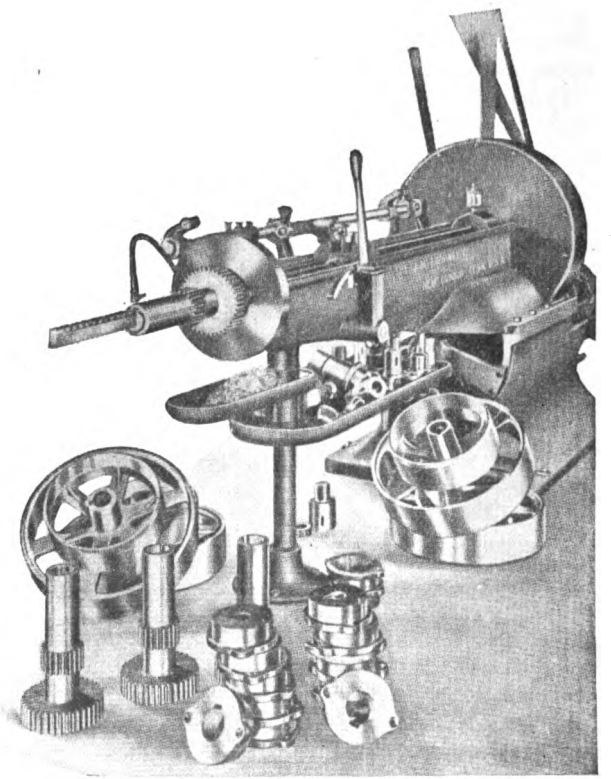


Fig. 389. Large Draw-Broaching Machine
Courtesy of J. N. Lapointe Company, New London, Connecticut

Design of Draw-Broaching Machines. Draw-broaching machines are made of various sizes and design. For light pieces having short holes, a small machine designed especially for such work,

should be used, as it can be made to produce work more rapidly than a heavy machine; but if heavy work with large or long holes is to be broached, it is necessary to use a heavy, strong machine with a long pull. A small broaching machine suitable for light work that must be handled rapidly, is shown in Fig. 387, and some

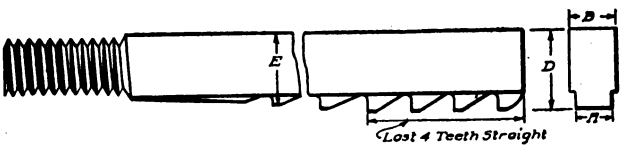


Fig. 390. Keyway Broach

samples of work done with it, are shown in Fig. 388. A much larger machine, with samples of work it is especially adapted for, is illustrated in Fig. 389.

Where a comparatively small amount of metal is to be removed by the broach, it is possible to produce a finished hole with one broach; but where considerable metal must be cut away, it is necessary to use two or more broaches, each a little larger than the one preceding it.

The time saved by draw-broaching keyways in long holes, as compared with methods formerly used, is apparent when one realizes that it takes but three minutes to produce a $\frac{5}{8}$-inch keyway 13 inches long by the use of two broaches. On shorter work, the keyways can be cut in one operation. Fig. 390 shows a keyway broach.

The ability of a broach to do a certain amount of work is generally governed by the amount of stock to be removed, as the indi-

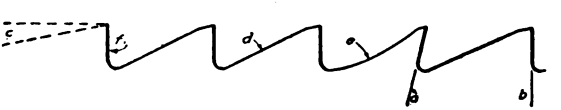


Fig. 391. Broach Teeth

vidual tooth must not cut away a greater amount of stock in the form of chips than can be held in the space between the teeth without interfering with the cutting. While it is customary to make broach teeth with their backs of the form shown at *d*, Fig. 391, at times it is necessary to give them the form shown at *e*, to provide a larger

chip space. The latter shape, however, does not give so strong a tooth as the former. Many times a round hole, the diameter of which is a little less than the smallest diameter of the finished hole, is drilled in the piece of work, and the hole brought to the desired size and shape by drawing the broach through it.

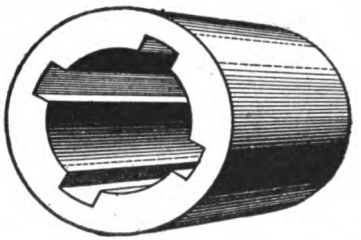


Fig. 392 Keyway Broached in One Operation

Illustrations of Broaching. The piece of work shown in Fig. 392, which has four $\frac{3}{8}$-inch keyways in a $\frac{1}{2}$-inch hole 3 inches long, is broached in one operation by the use of a four-spline broach.

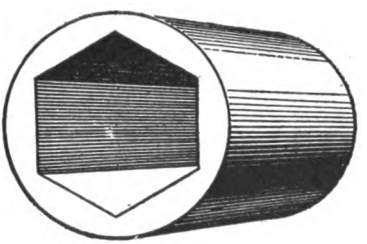


Fig. 393. Broaching Soft Steel at One Operation

The piece shown in Fig. 393, made from soft steel, is broached from a round hole in one operation by the use of one broach, the time necessary being one and one-half minutes. The broach is a hexagon $1\frac{3}{4}$ inches in diameter and the hole is 3 inches long. If harder stock is used, or longer holes broached, it may be necessary to use two, or even three broaches to produce a satisfactory hole.

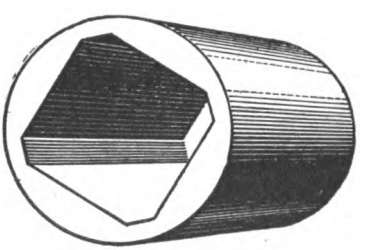


Fig. 394 Broaching Square Holes

Square holes are often broached in gears and similar pieces at a single operation. As a rule these holes are made with round instead of square corners, Fig. 394. This form of hole is designed to give greater strength to the piece, and is used especially where the work is to be subjected to great strain, and where square corners would be a source of weakness. If necessary, the broach may be made to produce square corners.

While it is possible to broach a large variety of forms and sizes of holes at a single operation, yet for certain jobs—as, for instance, the piece of work shown in Fig. 395—several operations are required. A portion of the piece, that is one notch, is cut at a time, the work being held in an index fixture so designed that the piece can be turned one-sixth of a revolution after each broaching operation, and the process repeated until all six notches have been produced. The forging, which is 6 inches in diameter and $1\frac{1}{4}$ inches thick, had a hole 4 inches in diameter bored in it before the piece was taken to the broaching machine to be notched.

Fig. 396 shows how the teeth of an internal gear are produced by broaching with an index fixture. In doing this class of work, as in cutting keyways in round holes, it is customary to guide the broach with bushings. The bushings fit the hole in the work and receive the broach as shown in Fig. 389, or are attached to the machine and so guide the broach in the proper location.

We have shown but a few of the many varieties of work that are satisfactorily produced at a relatively small cost by draw broaching.

Fig. 395. Broaching that Takes Several Operations

Under certain conditions round holes are produced by round broaches instead of being reamed. This is satisfactory for some classes of work, and the cost of finishing to size is much less than by reaming.

Fig. 397 shows a broach which does no cutting. It is employed to size holes in Babbitt metal and other alloys used for bearings, where it is advisable to compress the metal to give good wearing qualities. The broach is drawn through the same as any broach, and leaves a smooth hole, true to size.

In a great many cases, broaches of various forms are made to start in a round drilled or cored hole; at other times the starting hole may be rectangular, Fig. 398, or of some other form where

the core may be drilled and broken out as shown at *a*, Fig. 399, or the rough holes may be produced in the die if the piece is drop-forged as shown at *b* The finished broached hole in the connecting rod, as shown in Fig. 398, is $4\frac{1}{2}$ inches long by $2\frac{1}{4}$ inches wide.

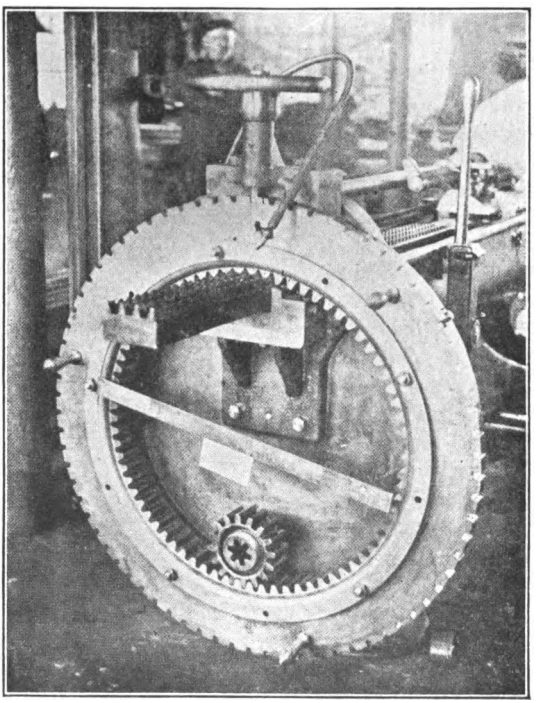


Fig. 396. Broaching Teeth of Internal Gear
Courtesy of J N Lapointe Company, New London, Connecticut

The length of the hole that can be broached with one broach is usually twice its diameter. For instance, if the broach is 1 inch square, it can be used to broach a hole 2 inches long. When the work is of greater length, two or more broaches are required, depending, however, upon the nature of the metal being broached, and

also upon the form of the broach, as the larger the round corner, the easier the pull on the broach. If absolutely sharp corners are

Fig. 397. Broach That Does Not Cut

made, the shorter will be the length of hole that can be broached, and, in case of long holes, the greater the number of broaches that

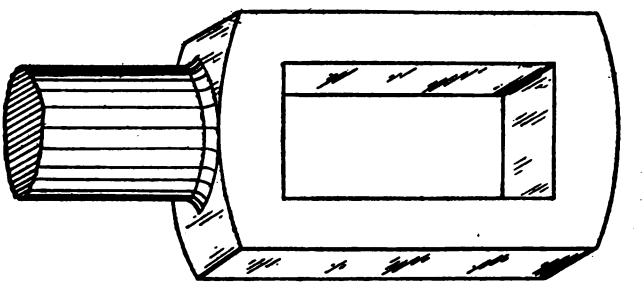


Fig. 398. Connecting Rod with Rectangular Starting Hole

must be used. The length of the hole that can be broached must be determined by the capacity of the machine.

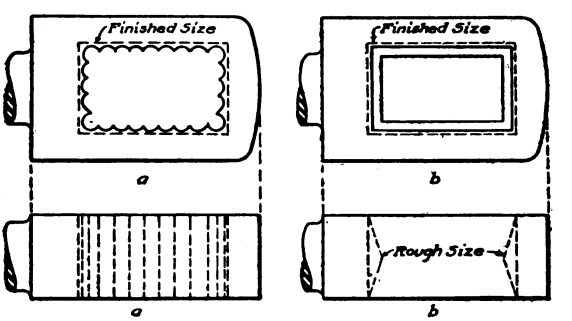


Fig. 399 Method of Broaching Rectangular Hole

Stock for Broaches. *Alloy Steel.* Broaches should, as a rule, be made from a good grade of crucible tool steel. Several of the alloy

steels work exceptionally well for broaches that are to be subjected to heavy pulls; this is especially true of vanadium tool steel, the vanadium renders the steel stronger and tougher, and its preence in the steel also increases the range of heat that can be employed when hardening, without augmenting the brittleness. The manufacturers of these steels recommend a hardening temperature of from 1350° F. to 1425° F., grading the heat according to the diameter of the broach. The temper should be drawn to a full straw color—460° F.

Oil-Hardening Steels. There are several oil-hardening steels that work well for many kinds of broaches. Their nature varies so much that it would not be wise to give specific instructions for their use. In case they are employed, it is best to obtain instructions for their treatment from the individual makers.

High-Speed Steel. High-speed steel is used for some classes of broaches, but it is not advised unless the designer is familiar with the limitations of this steel for this particular class of work. In some cases where conditions are favorable, high-speed steel broaches used on malleable cast iron give exceptionally good results.

Carbon-Tool Steel. Regular carbon-tool steel when used for draw broaches should ordinarily contain from 1.0 to 1.1 per cent carbon, although excellent results follow the use of steel containing 1.25 per cent carbon, if the pull is not too great; in the latter case, the lower carbon content is to be preferred.

Open-Hearth Steel. For broaches that are not to be subjected to great pulling strain, a good grade of basic open-hearth steel containing thirty points carbon works well, especially where the broaching is done directly from a cored or forged hole and where the broach is to be subjected to considerable vibration. Broaches made from this material must be pack hardened.

Making Draw Broaches. *Cutting and Turning to Size.* No general method can be given for making all forms of draw broaches, as the desirable method depends on the form of the finished tool If the broach is to be used for producing square, hexagonal, or other holes, with round corners, from a round drilled hole, select steel adapted to the individual job. Cut the steel to length, then center and square the ends; after which it should be rough-turned and the shank turned to finish size, which is generally the size of the

drilled hole. However, if the end of the shank is to fit some holding device that goes with the machine, then that portion must be turned to that size as shown in Fig. 400. This, of course, must not be larger than the drilled hole.

The balance of the piece should now be turned to the largest diameter of the broach plus a small amount for finish, and tapered

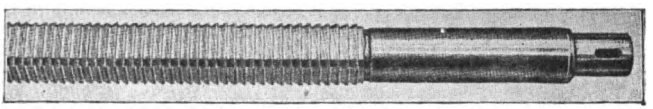


Fig. 400. Typical Pull Broach Showing Method of Holding End
Courtesy of J. N. Lapointe Company, New London, Connecticut

from the teeth nearest the fastened end to within four teeth of the opposite end; this end should be straight in order that the last four teeth may all be of a size to allow for wear, Fig, 390. Having the four teeth of finish size insures correct sizing of holes, even after the cutting teeth have been sharpened several times.

Annealing. Many tool-makers who make a specialty of broaching tools always anneal the broach after the teeth have been blocked out. After annealing, the teeth are cut to depth and the broach finished and hardened.

Cutting Teeth. If the broach is to produce a square hole with round corners, Fig. 394, the teeth may be first produced on the lathe on the round piece, Fig. 391, with a tool that will produce a cut of the desired form and depth. The spacing can be obtained by means of the lead screw, or, with a spacing block and clamp with a set screw, Fig. 401. The clamp should be attached to the bed of the lathe and the screw set against the space block as shown. The block, the thickness of which corresponds with the desired pitch of the teeth, is removed, and the carriage moved along against the screw. In this way, the

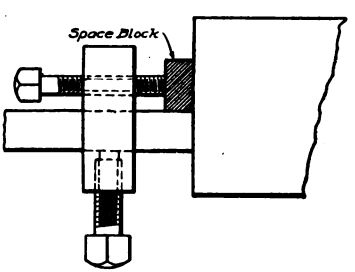


Fig. 401. Spacing Block and Clamp

teeth are spaced exactly alike for the entire length of the cutting portion of the broach.

Before the broach is removed from the lathe, the tops of the teeth should be backed off for clearance, as shown at *c*, Fig. 391, by means of a flat-nosed tool. After all the teeth have been backed off, the broach should be placed between the index centers of the milling machine, and one center raised or the other lowered to the taper of the broach and the flats milled. The large end—that is, the last four teeth—should be milled to the desired dimensions parallel to the axis.

The teeth on the flat portions may now be produced by milling or planing, to correspond in shape and depth to those on the round corners.

Filing Teeth. It is necessary to have the face and the back of the tooth smooth in order that chips will be cleared readily. This can be secured by filing, and should be done before the top surfaces that make the clearance angle are filed. Previous to filing the surfaces of the clearance angle, apply copperas in order that the workman may see where he is filing. File to the cutting edge, but do not remove any stock from the edge, because if one tooth is made short, the next tooth must do double duty. As previously stated, the four teeth at the large end of the broach should be of equal diameter if the tool is to hold its size.

Pitch of Teeth. The *pitch* of broach teeth cannot be stated arbitrarily, for the distance from one tooth to the next depends in a great measure on the amount of stock to be removed, the length of the broach, and the thickness of the piece to be broached. The following formula, however, is used by some manufacturers of broaches for use under average conditions:

$$P = \sqrt{L} \times 0.35$$

where P = pitch, or distance apart of teeth; and L = length of hole to be broached. For example, if a broach is to be made for broaching a hole 4 inches long, the distance between the teeth would equal 2×0.35, or .7 inch, approximately. In the case of a broach of large diameter, it is possible to cut the teeth deep and a little closer together than if the broach were of smaller diameter, as in the latter case the teeth must be shallower to give strength to the broach. It is always

necessary to design the broach with the teeth so spaced and of such depth that the space between them will hold the chips removed, for otherwise the chips would wedge themselves between the broach and the walls of the hole, thus tearing the surface of the walls, and in all probability breaking the broach.

Size of Teeth. The variation of size of adjoining teeth cannot be stated arbitrarily. Under average conditions, an increase in size of from .001 to .003 inch works well on steel, and from .002 to .004 inch on cast iron or brass. Yet working conditions and the character of the material make it possible and advisable to change these amounts of increase in size at times.

If the broach has long cutting teeth, it is advisable to nick them to break the chip, as the long chip, especially if it is steel, would be likely to cause trouble. When nicking the teeth, make sure that no two adjoining teeth have their nicks in line.

Angle of Teeth. The face *f*, Fig. 391, of the teeth of broaches is many times made at right angles to the axis of the broach. A tooth cut as shown at *a*, however, will require less force to pull it through the work if made at an angle, yet under ordinary conditions the shape shown at *b* is considered the better one.

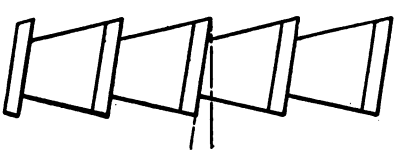


Fig. 402. Diagram Showing Angle of Broach Teeth

The clearance angle, *c*, is generally about 2 degrees, although at times but 1 degree is given.

The teeth of broaches are sometimes made at an angle, as shown in Fig. 402. In the case of square and rectangular broaches, teeth on opposite sides are made at opposite angles in order to balance the cut.

Hardening. When hardening broaches, it is necessary to heat them uniformly their entire length, a process best carried on in an oven furnace or in a piece of pipe in an ordinary furnace. In order to get a uniform temperature, the piece should be turned frequently. When it has become uniformly heated to the proper temperature, plunge it vertically in a bath of warm, not hot, water in which a quantity of salt has been dissolved, and work up and down until

cooled to the temperature of the water, when the broach may be removed and tested for straightness. If it has sprung in the operation of hardening, it may be straightened in the following manner: Place the broach in a screw press or a drill-press table on two blocks of *hard* wood, then, with a spirit lamp or bunsen burner, heat it until lard oil on the surface smokes; now, with a third block of wood between the work and spindle of machine, apply pressure by means of the spindle until the tool is straightened It will be necessary to do all the straightening before the temperature drops much, or the broach will break. After the straightening, the temper may be drawn. Some hardeners, who are quite skilful in this particular line of work, straighten and draw the temper at one operation. Broaches made from oil-hardening steels are heated as described above and hardened in oil. Broaches made from low-carbon open-hearth steel are packed in charred leather in a piece of gas pipe, the ends of which are sealed, and the whole subjected to a red heat for several hours, the time depending on the size of the piece. When the carbon has penetrated to the desired depth, the broach is removed from the pipe and plunged vertically into a bath of hardening oil; or, if a harder effect is desired, into a bath of lukewarm water.

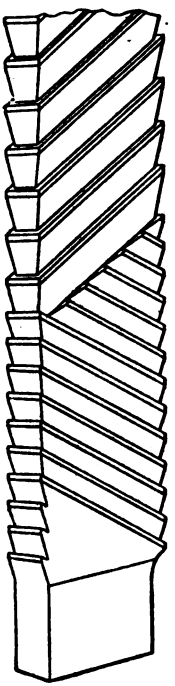


Fig. 403. Typical Push Broach

After hardening, the broach should be tested for straightness; if it has sprung, it should be heated and straightened, as previously described, and the temper drawn to a light straw color.

Long Broach vs. Short Broach. Generally speaking, the length of a broach depends on the amount of stock to be cut out of the hole, and the capacity of the machine. Some broach-makers, however, believe it is economy to use several short broaches instead of one long broach, even where the capacity of the machine makes it possible to use a long one, maintaining that long broaches are more costly to make, and more likely to break when

in use. The advisability of either depends on so many factors that are peculiar to the individual shop, that it is not possible to make any general statement that will fit all cases.

Push Broaches. Broaches of the form shown in Fig. 403, are called push broaches, and are used in special presses having an adjustable stroke of from 1½ to 12 inches. It is generally necessary to use several broaches in finishing a hole, especially if they are short. At times it is desirable to use a long broach in a press having a comparatively short stroke. This may be accomplished by using blocks. First drive the broach into the work as far as possible with the stroke of the press; then, when the ram is at the top of the stroke, insert a block the thickness of which is equal to the stroke of

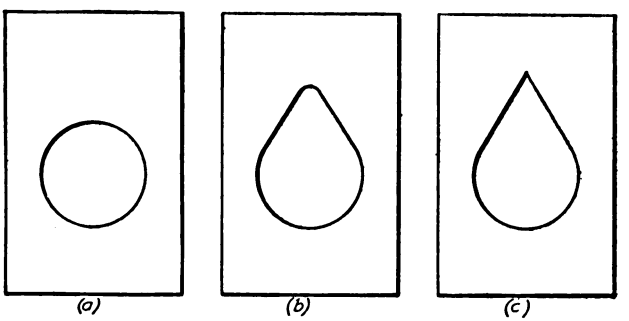


Fig. 404. Progressive Punchings of Keyseating Machine

the press between the ram and the top of the broach. At each successive stroke of the press, use a thicker block.

When broaches are used in a press, it is always advisable to use a driver having a V-shaped opening in face.

Keyseating Machine. For many jobs a keyseating machine is an absolutely essential part of the equipment. Where work is done in small lots, it is frequently advisable to use this machine instead of a broaching machine, as the cost of cutting tools is but a fraction of the cost of a broach.

At times this machine is used to remove a portion of the stock before broaching, as is the case with the piece shown in Fig. 404. A hole is drilled in the piece, as shown at *a;* the piece is then placed in the keyseating machine and the hole cut to the form shown

at *b*, after which it may be brought to finish size and shape *c* by broaching.

Irregularly shaped holes that are larger at one end than at the other, as shown in the circular piece, Fig. 405, are easily

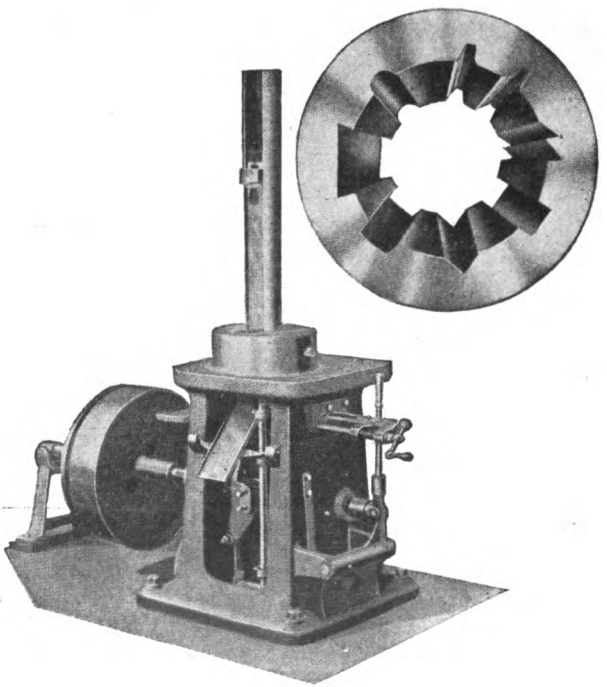


Fig. 405. Keyseating Machine and Sample Keyseats in Taper Hole
Courtesy of Mitts and Merrill, Saginaw, Michigan

machined in a keyseating machine by the use of properly shaped cutting tools and rightly designed holding fixtures.

DROP-FORGING DIES

It is extremely difficult, as well as very costly, to produce many forgings by hand, if it is necessary that they be of uniform size and form. As the tendency in all up-to-date shops is to produce

duplicate work, and many parts are turned out by forging, dies are made which have the shape of the piece to be forged cut into the faces. A forging of the desired size and shape is produced by forcing the heated metal into the impressions.

Drop-Forging Process. In forging, the dies may be held in forging machines of various kinds, such as the *forging press*, the *bulldozer*, the *drop press* (where the ram is raised by means of rolls acting on a board attached to the ram or head), or the *steam drop*, Fig. 406. Although the *board drop*, Fig. 407, is the form most commonly used, it is giving way in many places to the steam drop on account of the more positive and speedy action. It is frequently necessary to use several sets of dies, or several sets of impressions in the same dies; *first*, a breaking-down impression; *second*, a roughing impression, and *third*, a finish impression.

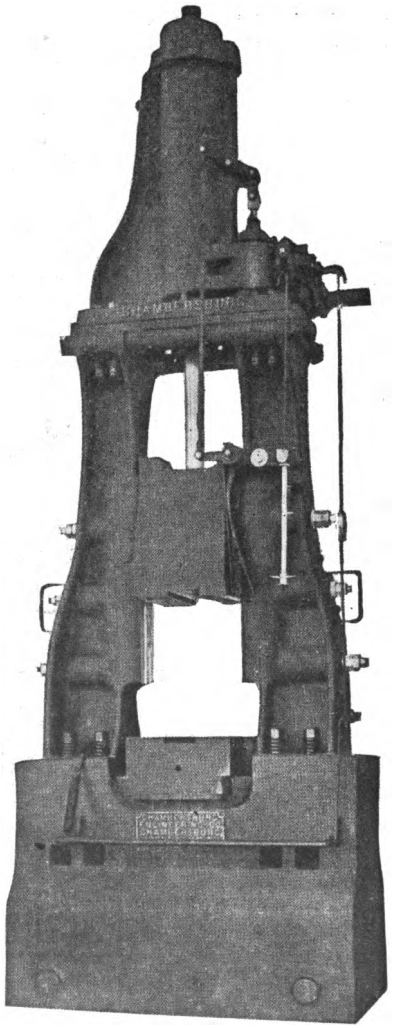


Fig. 406. Chambersburg Steam Drop Hammer

Considerable experience, coupled with good judgment, is required to lay off properly a breaking-down impression in a

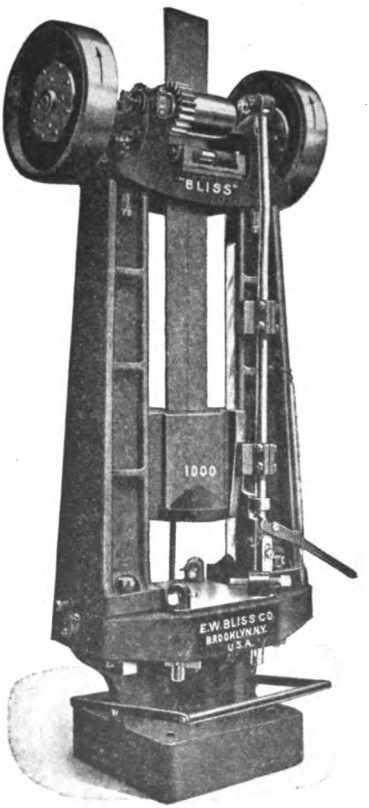


Fig. 407. Board Drop Hammer
Courtesy of E. W. Bliss Company, Brooklyn, New York

forging die, in order that the material may be rightly distributed so as to fill the other impressions without excessive waste of stock.

A die-maker with limited experience in laying out dies should give special attention to the laying out of breaking-down impressions in order that he may be able to do this kind of work in a satisfactory manner.

After forging, a quantity of surplus stock will show around the desired blank; this is called the *flash*. The flash is removed by forcing the forging through a *trimming die*. The impression in the trimming die is the exact shape of the forging, and the forging passing through has the flash cut away. Large forgings are trimmed while red hot, and the operation is known as *hot trimming*, while small forgings are generally trimmed cold, and the process is called *cold trimming*.

Making Drop-Forging Dies. *Stock.* Drop-forging dies are made from crucible steel which is furnished in the form of die blocks in any desired size; or, as is the case in many shops, they are made from open-hearth steel, in which case they are procured from the mill in pieces of the proper size, or the stock is purchased in bars and cut up and forged to size as wanted. The latter method proves satisfactory where the equipment of the shop allows the heating and handling of pieces of metal weighing several tons. As it is then possible to cut off, forge, and anneal pieces of almost any size, there is very little waste.

Small dies are generally hardened, while large dies seldom are. Large dies that are not to be hardened are often made from steel containing a proportion of nickel, or other alloy that insures desired ability to stand up when in use.

Cutting. Most die blocks are planed to size after annealing, although in some shops they are milled to size. The tang is produced by either planing or milling, according to the equipment of the shop. The impressions are carefully laid out on the faces of the dies by means of templets, and the metal cut away with milling machine cutters, the work being done in a die-sinking machine. The cutters are made of a taper that produces the proper draft in the die. It is necessary to give the impression sufficient draft so that the forging will not stick in the die. The draft which should be used varies from 3 to 5 degrees.

As it is not possible to get into corners with milling cutters, it is frequently necessary to remove some of the stock with a cold

chisel, scraper, and files. Die-sinkers use a special type of file in working the walls of the impressions; these are of various forms and are bent to allow of use in the impressions. They are called *rifflers*. In Fig. 408 are shown various special forms of files and rasps.

Casting Lead. After the impressions in the die are finished to size and shape, the dies are clamped face to face, and lead is poured

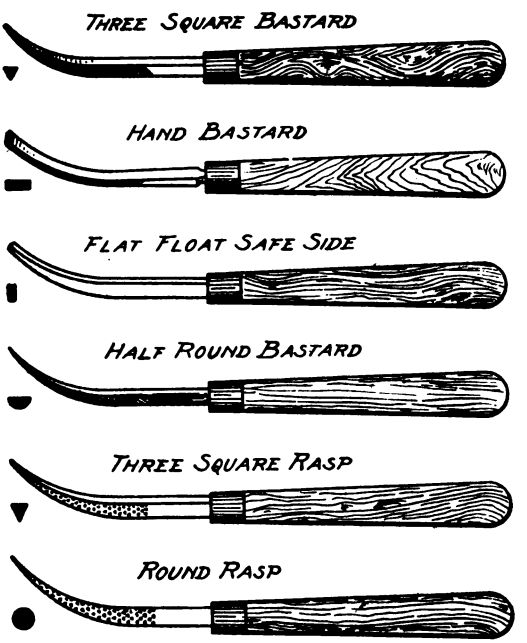


Fig 408. Special Forms of File and Rasps

into the impressions. The resulting piece, known as the lead, is measured, and, if found correct, is marked and laid away for reference. In some shops the die faces are blocked apart when the lead is cast. After casting, the blocking is removed, the dies are placed in a hydraulic press, and the lead is forced out into all parts of the die; if a flash is thrown out between the dies, this may be cut away and the lead pressed again. As a rule, the pressing of a lead is not

the practice, as it is necessary to allow for shrinkage and this involves the use of tables of coefficients of expansion of metals.

If the lead, when measured, is found not to be of the desired size, sufficient stock may be removed to give desired results, and another lead cast.

For many dies, it will be found necessary to cut away the faces of the dies around the impressions, Fig. 409, to provide a place for the flash, in order that it may not lie between the dies, and so produce forgings of varying thickness.

Stamping Identification Marks. When the die blocks are finished, and before they are hardened, the name of the piece to be forged in the die, as well as the shelf number of the die, should be stamped on one or both ends of each. While this might not seem necessary in the shop having only ten or twelve sets of dies, it *is* necessary in the shop having hundreds, some of which are seldom used. If the dies are kept in a certain place on certain shelves, and a record is kept of the dies and the shelves, it is an easy matter to find any die, at any time.

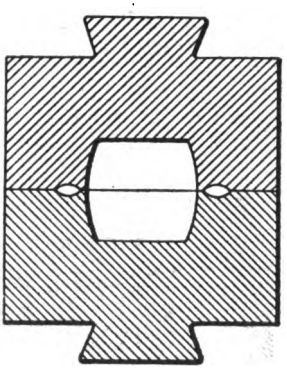


Fig. 409. Die with Faces Cut Away to Provide for Flashes

Hardening. When hardening drop-forging dies, it is necessary to employ some form of heating furnace that will insure heats of the proper temperature—in other words, a furnace that can be easily and quickly regulated. The die should be heated rapidly, yet not faster than is consistent with uniform heating, or the corners and light sections will be overheated and weakened.

If large pieces of steel are placed in a furnace and allowed to remain exposed to the direct heat and to any air that may be in the furnace, their surfaces are likely to become decarbonized. As the faces and walls of the impressions of forging dies must be hardened, it is desirable to protect them. This is sometimes done by placing a quantity of granulated charcoal in the furnace on the hearth, and laying the face of the die on this. A more satisfactory method

consists in placing one or two inches of granulated charred leather in the bottom of a shallow hardening box, laying the face of the die on the leather, then filling the box with leather, as shown in Fig. 410

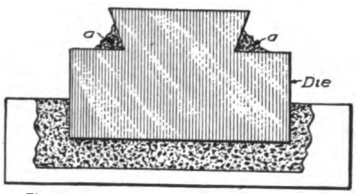


Fig. 410. Hardening Box with Die in Charred Leather

The die may then remain in the furnace until it is uniformly heated throughout. To prevent unequal heating in the corners at base of the tang, the corners are filled with fire clay, as shown at *a*.

The form of bath depends somewhat, of course, on the character of the pieces to be hardened. One form that is satisfactory for most work of this kind, has the die resting upon the supporting wires, Fig. 411. The overflow pipe should be telescoped, thus enabling the operator to regulate the depth of water in the tank. To prevent the tang from becoming distorted, it is advisable to quench this portion first; this is accomplished by placing the die, tang down, on the wires, and allowing the stream of water from the supply pipe to play against the tang. The die should be left in this position until the tang is cooled below a red, when the die should be turned to bring the face down, and the supply stream allowed to play against this portion until it is hardened.

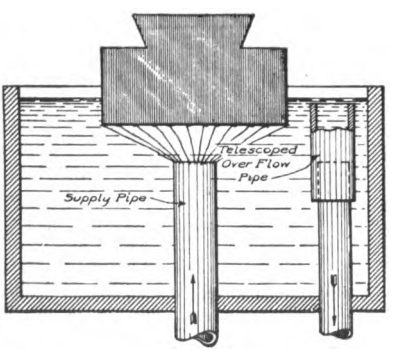


Fig. 411. Form of Hardening Bath with Die on Supporting Wires

To prevent the tang from softening before the face becomes hard, turn water, by means of a dipper, on to the tang until the red has disappeared from the face; then cease pouring on to the tang and allow the heat to work from the center of the block up through the tang, which will in all probability be reheated to a low red.

After the block has cooled, it should be placed over a fire and heated to remove hardening strains. While heating, the surface may be brightened and the heat continued until the temper is drawn the desired amount.

At times it is necessary to harden a die having slender projections or some weak portion which is likely to crack during the process. Cracking results from the unequal contraction of the various parts, and can be avoided by rubbing soap on the projection, especially where it joins the die; or, by means of an oil can, a little lard or sperm oil may be applied to these parts. This should be done after the die is red hot, and just before it is placed in the bath. If the

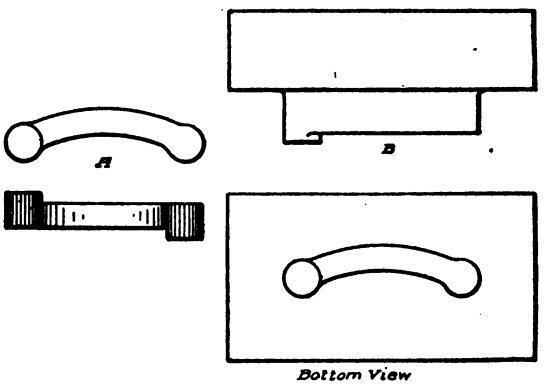


Fig. 412. Hobbing Drop-Forging Dies. *A*—Piece to be forged; *B*—Hob

tang is quenched first, the oil may be applied just before the die is turned to harden the face.

Hobbing Drop-Forging Dies. It is the custom in some shops to produce the impression in the face of forging dies with a male die, or hob, as it is called. A hob is made of the same general shape as one-half of the piece to be forged, but exactly opposite the shape of the impression desired in one die. Another hob is made the shape of which is the opposite of the impression desired in the other blank.

Making Impression. Fig. 412 shows a piece to be forged, *A*, and a hob, *B*. The hob has a shank that fits a holder in the ram

of the drop hammer. The hobs are hardened before using, and after hardening, one of them is placed in the holder in the ram; the die block is heated to a good forging heat and securely fastened to the anvil of the drop, and the hob is driven into the face of the die. This operation is repeated until the impression is considerably deeper than that desired when finished. This is necessary as the top surface of the die must be cut away to remove the rounded portion at the top of the impression, occasioned by the stock drawing away in the hobbing.

Cleaning and Smoothing Impression. After driving the hob to the required depth, the block is reheated and annealed. When the block has cooled, the scale on the surface of the walls of the impression is removed by filling the impression with a solution of sulphuric acid and water—one part acid, and two parts water. After the scale has been removed, the acid should be turned out and the surface well washed, first with hot water, then with a strong solution of potash, and then, once more, with water. The surface, when dry, should be oiled to prevent rusting.

Cold-Dropping Impression. The walls of the impression may now be finished smooth with scrapers and files. After the surfaces are finished, it is the custom in some shops to cold-drop the impression, that is, to place the die in the drop hammer again and drop the hob into the impression while the steel is cold. This custom, however, is not generally observed. After finishing, the dies are hardened in the usual manner.

Preventing Oxidation. A saving in labor may be effected, if, when the die is heated for annealing, the impression is filled with fire clay mixed with water to the consistency of dough. The fire clay prevents the air coming in contact with the steel, and does away, to a great extent, with oxidation.

Cold-Striking Dies. Many times pieces are forged which cannot be brought near enough to desired size by hammering when hot; or which must be much stiffer than hot-forging would leave them. In such cases cold-dropping or cold-striking, as it is sometimes called, must be resorted to.

After the pieces are hot-forged to a size slightly larger than finish, and the flash is trimmed away, they are pickled to remove the scale incident to the high forging heats. After pickling, and

when they are cold, they are again taken to the drop hammer and given one or more blows, in dies known as cold-striking dies.

The impression in a cold-striking die is made of the desired size of the finish piece, as no allowance need be made for contraction of the metal as is necessary when hot-forging. Since there is much greater strain on a cold-striking die than on one used for hot-forging, it is necessary to harden the former much deeper than the latter to prevent sinking when the die is used. For this reason, the dies should be made from steel having a comparatively high-carbon content.

While a large percentage of dies used for hot-forging are made from open-hearth steel, those used for cold-dropping are made from crucible tool steel. In many forging plants, this class of die is made from alloy steel prepared specially for this purpose; in such cases the heat treatment may be somewhat different from that given similar dies made from crucible tool steel. As the treatment varies for steels of different makes, it is necessary to follow the instructions furnished with the steel.

GAGES

Gages are used in machine shops to make one part of a machine, apparatus, or tool correspond with some other part, so that when the whole is assembled, every part will go in its place with little or no fitting.

In shops where work is made on the interchangeable plan—that is, where a piece of work made today will exactly duplicate a similar piece made at some time in the past—a very thorough system of inspection is necessary. In order that the inspection may accomplish the desired result, gages are made that show any variation of the pieces from a given standard. There are several forms of gages designed for various classes of work, but only those in common use in the general machine shop will be considered here.

General Directions for Making Gages. Gages are generally made of tool steel; but hardened steel has a tendency to change its size or shape for a considerable time after the hardening has occurred. This change is ascribed by acknowledged authorities to a rearrangement of the minute particles or molecules of the steel, whose original arrangement had been changed by the process of

hardening. While this change of size or shape is small, so small, indeed, that it need not be considered, except in the case of gages where great accuracy is required, yet it has led some manufacturers to use machine steel.

If tool steel is used, the tendency to change shape may be overcome to some extent by grinding the gage to within a few thousandths of an inch of finish size, and allowing it to "season" as it is termed among mechanics; that is, it is laid aside for a few months or a year, before being finished to size. This method is, of course, open to serious objection if the gage is needed for immediate use.

To save time, it is customary in many shops to draw the temper to a straw color, allowing the gage to cool slowly and repeating the operation several times. It is necessary to brighten the steel each time before drawing the temper in order that the colors may be readily seen; as this has a softening effect, the gage will not last so long as if left hard.

Accuracy Required. When making gages the workman should observe the points emphasized with regard to "approximate and precise measurements" in the first pages of this book. While gage-making is generally considered very accurate work, unnecessary accuracy should not be used. If a gage is intended for work where a variation of .005 inch is permissible, it is folly and a waste of time to attempt to make it within a limit of variation of .0001 inch. On the other hand, if the gage is to be used as a test gage on work requiring great exactness, it is necessary to use every possible effort to attain that end.

If a gage is to be made of tool steel, it is necessary first to remove all the outside portion (skin) of the stock, and block the gage out somewhere near to shape; it should then be thoroughly annealed. If the gage is flat and should spring while annealing, it should *not* be straightened cold, as it would be almost sure to spring when hardened.

It is necessary to stamp the name of the part to be gaged and the sizes of the different parts of the gage. The workman should bear in mind that the effect of driving stamps, letters, or figures into a piece of steel will be to stretch it; consequently, it is advisable to stamp the gage before finishing any of the gaging portions to size, even if there is an allowance for grinding.

Plug Gages. Plug gages are those used to measure the size of a hole.

To make the plug gage shown in Fig. 413, stock should be selected enough larger than finish size to allow for turning off the decarbonized surface. After roughing out, the handle *B* should be turned to size and knurled, the portion *C* should be turned to size and finished, and the spot in the center of the handle should be milled. The size of the gage and any distinguishing mark or name of the article to be gaged may be stamped at *B*, as shown, or, as is the custom in many shops, it may be done at *C*. After stamping, the gage end *A* may be turned to a size .010 or .015 inch larger than finish, to allow for grinding. Plug gages should be heated very carefully for hardening, as the lower the heat, the more compact will be the grain; and a piece of steel whose grain is fine and compact will wear better than one whose grain is coarse. If the gage is one requiring great accuracy, it may be left .0025 or .003 inch above size and allowed to season, provided this precaution is deemed necessary; if not, the gage may be ground to a size .001 inch larger than finish, after which it must be lapped to finish size.

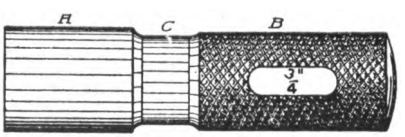


Fig. 413. Typical Plug Gage

Casehardening Machine-Steel Gages. When plug gages are made of machine steel, they should be casehardened in the following manner: They may be packed as for pack hardening, that is, in charred leather. They should run in the furnace for seven or eight hours after they are red hot. The box should then be taken from the furnace and allowed to cool, after which the gage, enclosed in a piece of tube, may be heated in an ordinary fire. When it reaches a low red heat, it should be plunged into a bath of raw linseed oil. It will not be necessary to draw the temper, and the danger of alteration as it ages is done away with.

The reason for not hardening when the gage has run the required length of time in the furnace, is that the effect of the second heat is to refine the steel, making the grain more compact, like properly hardened tool steel, thus increasing its wearing qualities.

Grinding. When grinding a gage of this description, it is advisable to use a grinding machine having a supply of water running on the work to keep it cool, but if this form of grinder is not available, the gage should not be heated any more than is necessary. It should be measured while cool, as steel always expands from the action of heat, and if ground to size when heated, would be too small after cooling.

If possible, a form of grinder having two dead centers should be used—that is, one in which neither center revolves. This is mentioned on account of the tendency in some shops where there is no universal grinder, and an engine lathe is to be used as a grinder, to select the poorest lathe in the shop for the purpose. Lathes that have been in use for some time are very likely to have become worn, so that accurate work is impossible; this is especially true

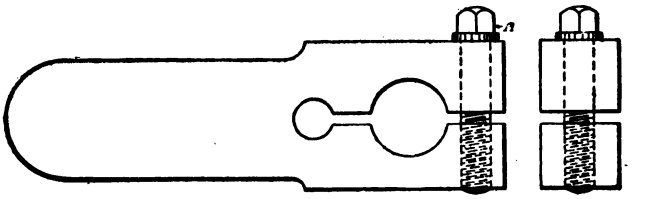


Fig. 414. Good Form of Lap for Cylindrical Surfaces

of the head spindle, which will duplicate its own inaccuracy on the piece being ground.

If obliged to do the work on a machine of this description, it is advisable to leave a trifle more stock for lapping than if a suitable grinder is used. A coarse wheel free from glaze should be employed to grind within .004 of finish size, after which a finer wheel may be substituted to grind to lapping size.

Lapping. A very simple method of making a lap for use on a cylindrical surface is shown in Fig. 414; this consists of a piece of cast iron having a hole bored a trifle larger than the size of the gage to be ground. It is split as shown, and closed by means of the screw *A*.

If there is much gage or other work requiring lapping, it is advisable to make a lap as shown in Fig. 415. The holder *A* has a

hole bored to receive the laps, which are made in the form of rings, split in three places, which fit the holder. One cut is carried through one wall; while the other two, commencing at the inside, terminate

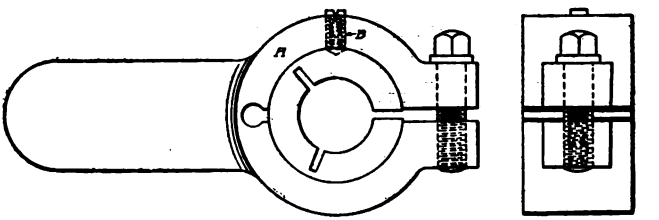


Fig. 415. Lap for Gages

a little distance from the outside surface. The laps may be held in place by means of the pointed screw shown at *B*.

The lapping should be done with flour emery mixed with oil. This operation has the effect of heating the gage to a degree that would make it unsafe to caliper, and on this account it is necessary to have a dish of water handy in which to cool the gage before measuring it. This water should not be *cold*, or incorrect measurements will result; it should be as nearly as possible the average temperature of the room in which it is to be used, about 70 degrees.

Grinding Off End. After the tool has been lapped to the required size, it may be placed in a chuck on the grinding machine and the end ground off to remove any portion that is slightly smaller than the rest of the gage, as the lapping is likely to grind the extreme end slightly tapering. In order to save time when grinding the end,

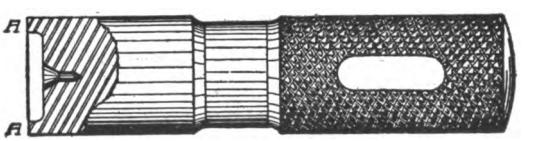


Fig. 416. Lap with Cupped End Which Is Later Ground Off

the gage may be made as shown in Fig. 416. The sectional view shows the end cupped in, leaving a wall $\frac{1}{16}$ inch to $\frac{1}{8}$ inch thick, according to the size of the gage, the larger sizes having the thicker

walls; the cupping should be about $\frac{1}{16}$ inch deep and the corner left slightly rounded, as shown.

Another method is to cut a groove with a round-nosed cutting-off tool, leaving a disc on the end, Fig. 417. If the gage has its end shaped as in Fig. 416, the projecting portion, *AA*, is ground away until the end of the gage is straight across. In case the gage is made as shown in Fig. 417, the disc *A* is broken off and the end ground as described.

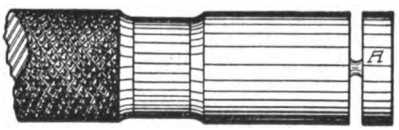


Fig. 417. Gage with Disc on End Which Is Broken Off and Ground Down

Ring Gages. *Ring gages* are intended for use on cylindrical pieces of work. Those which are smaller than one inch in diameter are generally made of a solid piece of tool steel, or machine steel which is casehardened. For a gage one inch or larger, custom varies, some tool-makers making it of a solid piece, while others make the body of cast iron or machine steel, into which is forced a hardened steel bushing which is the gage proper.

Boring Holes. It is advisable, when making a solid gage, to use a piece of steel somewhat longer than finish dimensions, as shown in Fig. 418, the dimension *A* representing the finish length

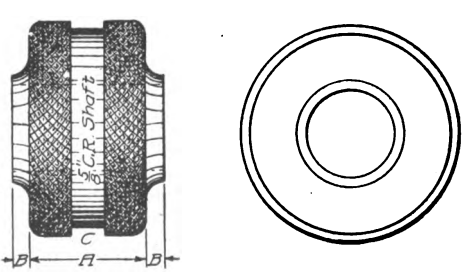


Fig. 418. Ring Gage

of gage, and the projections *BB* being left until the gage is lapped to size. The hole should be bored somewhat smaller than the finish size, in order to allow for grinding and lapping. If a grinder having an internal grinding attachment is not available, the allow-

ance should be much less than if it were possible to grind the walls of the hole. If the gage is to be ground to size, an allowance of .005 inch will be about the proper amount; if not to be ground and the hole is bored straight and smooth, an allowance of from .0015 to .002 inch should be made; but the amount left cannot be given arbitrarily, as much depends on the condition of the hole and the care used in hardening.

Hardening. After the hole has been bored, the blank may be placed on a mandrel, the ends shaped as shown in Fig. 418, the outside diameter turned and knurled, and the portion *C* necked to the bottom of the knurling. The size and any distinguishing marks may be stamped on this necked portion as shown. The gage is now ready for hardening, and much the best results are obtained from pack hardening. If this method cannot be used, the gage should be carefully heated in a muffle furnace or in a piece

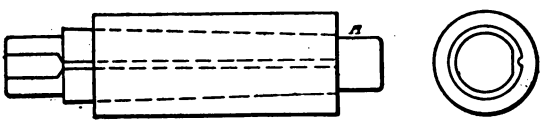


Fig. 419. Lead Lap on Mandrel

of gas pipe or iron tube in an ordinary fire. When it reaches a low uniform heat, it should be plunged into a bath of brine and worked around so that the bath may circulate freely through the holes. Excellent results follow if a bath is used having a jet of brine or water coming up from the bottom and passing through the hole with some force, in order to remove any steam that may be generated.

Grinding. If it is considered necessary to allow the gage to season, the hole may be ground enough to remove part of the allowance, and the gage laid away. If it is not considered necessary to do this, it may be ground .001 or .0015 inch smaller than finish size to allow for lapping.

Lapping. When lapping a ring gage to size, it is necessary to use a good lap. A poor lap is the cause of many of the failures when attempting to do satisfactory work of this description.

When a grinder with an internal grinding attachment is not available, and it is found necessary to leave considerable stock in the hold for lapping, many tool-makers claim best results from using two

laps—the first, a *lead lap*, for removing most of the stock, and the second, a *cast-iron lap*, for finishing the hole to size. In either case, the lap should be in the form of a shell which should be held on a taper mandrel when in use. Fig. 419 shows a lead lap on a mandrel as described.

The mandrel should be made with the ends somewhat smaller than the body, which should be tapering, in order that the lap may be expanded as it is driven on. A groove is cut the entire length of the body with a convex milling cutter, or it may be cut in the shaper or planer, holding the mandrel between centers, or in the vise, cutting the slot with a round-nosed tool. A mold for casting the lead to shape may be made of two pieces of wood an inch or two longer than the desired length of lap, which itself should be three times the length of the hole in the gage. The two pieces of wood should be clamped together, and the hole bored with a bit about $\frac{1}{8}$ inch larger than the diameter of the finished lap; after boring to the required depth, a bit should then be used the size of the projection on the small end of the mandrel. The hole bored with this bit should be a trifle deeper than the length of the projection. After the hole has been bored in the mold, as described, the mandrel may be put in position, Fig. 420, with the mold vertical. Two narrow strips of wood or metal are placed on top of the mold to hold the mandrel central and the lead is poured. In order that the lead may run well, it will be necessary to heat the mandrel somewhat; this should be done before putting it in the mold. After the lead has become cool, the mold may be opened, and the casting removed. It should be placed in the lathe on the mandrel, and turned to a size .001 inch smaller than the hole in the gage; it may then be charged with fine emery and oil.

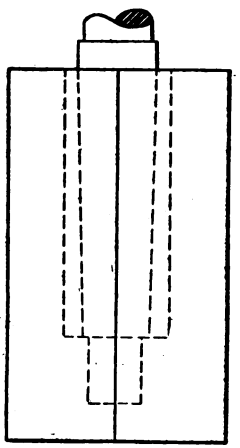


Fig. 420. Mandrel in Mold

For finishing the hole to size, or lapping a hole ground nearly to size, it is advisable to use a lap made of harder material than lead;

for this purpose fine-grained cast iron answers admirably, although copper is preferred by some. In order to make a cast-iron lap, a mandrel is necessary, with a taper from $\frac{1}{8}$ to $\frac{3}{16}$ inch per foot of length. The slight taper is used in order that the lap may not increase its size too rapidly when driven on the mandrel. The cast-iron lap (sleeve) should be bored with a taper corresponding to the taper of the mandrel, after which it may be forced on the mandrel and turned to size and split as shown in Fig. 421. One slot should extend through the wall as shown at *A*, while the other two slots *BB* extend deep enough to allow the lap to expand readily. Before finishing the hole to size, the lap should be forced a trifle farther on the mandrel, and trued in the grinder, an emery wheel being

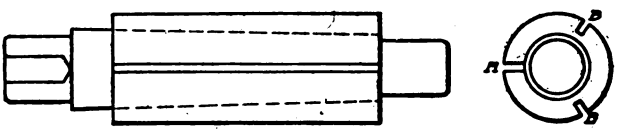


Fig. 421. Lap Forced on Mandrel and Split

used to cut the lap. The lap should be perfectly round and straight, in order to produce true holes. For the finish lapping, the finest of flour emery should be used.

Finishing Gage. The same precautions should be observed while cooling the gage before trying the size of hole, as were noted for plug gages. In order to clean the gage of the oil and emery, it should be dipped in a can of benzine, which readily removes any dirt. Extreme care must be exercised when washing work in benzine, that it is not brought into the vicinity of a flame of any kind, as benzine is extremely inflammable, and very difficult to extinguish if it becomes ignited; should it become ignited, it can be extinguished with a piece of heavy sacking.

The ring should be fitted to the plug gage which has previously been finished to the correct size. It must be borne in mind that the temperature of the plug and ring should be as nearly as possible the same when tested.

Snap Gage. This form of gage is used more extensively than any other for outside measurements. It is extremely useful in gaging a dimension between two shoulders as shown at *A*,

Figs. 422 and 423; in the former case, the piece being machined is flat, while in the latter it is cylindrical.

A snap gage may be designed to meet the requirements of the particular piece of work. When it is intended for use on a cylindrical piece, the opening should be made a trifle deeper than one-half

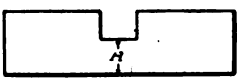


Fig. 422. Flat Piece Easily Gaged with Snap Gage

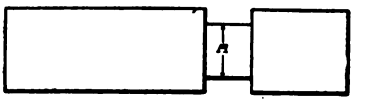


Fig. 423. Cylindrical Piece Adapted to Use of Snap Gage

the diameter of the piece to be measured, when it is intended for flat work, the depth of the slot depends on the nature of the work.

Snap Gages for Cylindrical Work. A gage of this type is shown in Fig. 424, *A* representing the cylindrical piece to be gaged. When making this gage, the stock should be blocked out somewhat near to shape and annealed; after annealing, the sides may be made flat and parallel; and the size and any distinguishing marks stamped as shown; the gage part may then be worked to a size from .008 to .010 inch smaller than finish, to allow for grinding. The outer edges should be rounded somewhat to prevent cutting the hands of the operator.

Some tool-makers harden only the prongs that come in contact with the work, while others harden the entire tool. If the contact points alone are to be hardened, the heating can best be done in a crucible of red-hot lead; if this is not at hand, pieces of flat iron may be placed, one on each side of the gage, allowing the ends to be hardened to project beyond the pieces; the whole may now be grasped in a pair of tongs and placed in the fire. The points will reach a hardening heat before the portion between the flat pieces is much affected. The gage may be plunged in water or brine to harden. If it is considered advisable to harden the gage all over, it should be heated very carefully in the fire, so that the blast does not strike it, and turned frequently to insure a uniform heat. When it reaches a low red heat, remove it from the fire and plunge

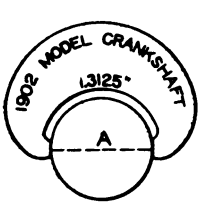


Fig. 424. Snap Gage

it into the bath. If the gage is quite thin, a bath of oil will harden it sufficiently; if it is dipped in water or brine, the bath should be warmed somewhat in order to avoid, as much as possible, any tendency to spring.

After hardening, the gage is ground to size .0005 inch smaller than finish and lapped to size; the method used in grinding gages of this character will be described later.

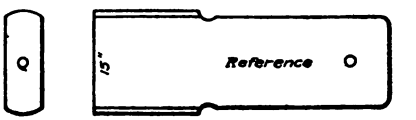


Fig. 425. Male Gage

Male Gages for Testing Snap Gages. In order to be able to give gages the correct size, it is often necessary to make male gages, the simplest form of which is shown in Fig. 425. It is a flat piece of tool steel, made slightly small on one end to avoid grinding to size the entire length. After the large end has been hardened, it is ground to size and the gage is then ready for use in testing the size of the female snap gages while the latter are being lapped to size, or when being ground, if lapping is not considered necessary. When it is necessary to make a snap gage for measuring two or more dimensions on a piece of work, it may be made as shown in Fig. 426. Fig. 427 represents the piece to be gaged.

After cutting off the steel for the gage, the sides should be planed to remove the skin. One of the flat surfaces may be colored either

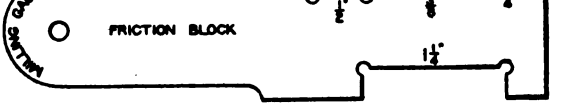


Fig. 426. Snap Gage Giving Several Measurements

with blue vitriol or by holding it over a fire until the surface becomes blue. The handle and the openings that constitute the gages can then be laid off on the surface. After milling the handle to shape, the holes shown at the corners of the openings may be drilled. These holes facilitate the operations of filing and grinding, particularly the latter. The openings may be milled or planed to a size about

$\frac{1}{32}$ inch smaller than finish, and the gage is ready for annealing, after which the two flat surfaces may be planed or filed until flat and parallel. The name of the piece to be gaged and the size of the openings may be stamped as shown. If the tool is intended for gaging work where a few thousandths of an inch either way would make no particular difference, it is customary to make the openings to the given sizes before the gage is hardened. However, if the gage must be exact to size, it is necessary to leave from .003 to .005 inch on each measuring surface, to allow for grinding. If it is desirable to have the gage retain its exact size for any considerable length of time, it will be found necessary to finish it to size by lapping after it is ground.

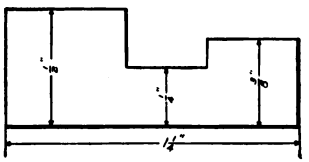


Fig. 427. Friction Block

Grinding Snap Gages. A snap gage may be held in a vise on the universal grinder when the openings are ground to size, provided it is held in such a way that it cannot spring. If sprung in any manner while being held, it would assume its normal shape when taken from the vise, and consequently the measuring surfaces would not be parallel. As this would destroy its accuracy, it is highly important that the measuring surfaces of the openings be parallel.

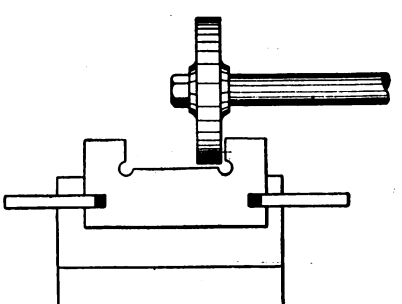


Fig. 428. Snap Gage Clamped in Vise for Grinding

A snap gage may be clamped to an angle iron held in the vise while grinding, Fig. 428, or it may be clamped to a piece of machine steel or cast iron centered, Fig. 429. This holder should be placed between the centers of the grinding machine.

If the opening whose gaging surfaces are to be ground is of sufficient width, an emery wheel of the form shown in Fig. 430 may

be used; or a wheel may be recessed on its sides as shown in Fig. 431. If the wheel is of the form shown in Fig. 430, it will be necessary

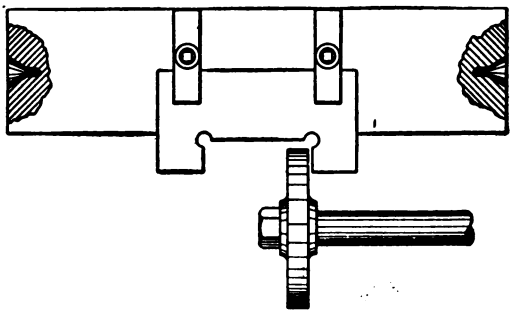
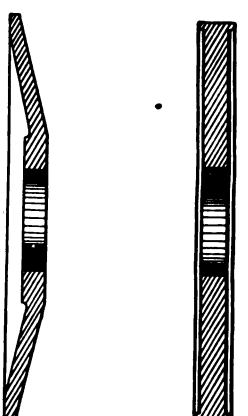


Fig. 429. Snap Gage Clamped to Centered Piece

to remove it after grinding one wall of the opening and to reverse it to grind the other. If, however, the opening is too narrow to allow this type of wheel, a very thin wheel may be made to answer the purpose, but it will be necessary to swivel the head of the grinder a little, in order that the wheel may touch the surface to be ground only at the corner of the wheel. An engine lathe or a bench lathe can be substituted if a grinding machine is not available. If the lathe is provided with a grinding attachment, the holder to which the gage is attached may be placed between the centers of the lathe, and the grinding attachment used in the ordinary manner. If the lathe is not provided with a grinding attachment, the emery wheel may be mounted on an arbor between the centers of the lathe. The arbor may be driven from any accessible pulley, either on some overhead countershaft or else on some machine whose driving pulley is in line with a small pulley on the arbor. If



Figs. 430 and 431. Typical Wheels for Grinding Gages

this method is used, it will be necessary to have hardened centers in both head and tail spindles of the lathe.

A thin wheel used in grinding the surfaces of a narrow opening necessitates that the tail center of the lathe be set over each way to give the desired amount of clearance to the side of the emery wheel. The holder mentioned may be fastened to the tool rest, or the gage

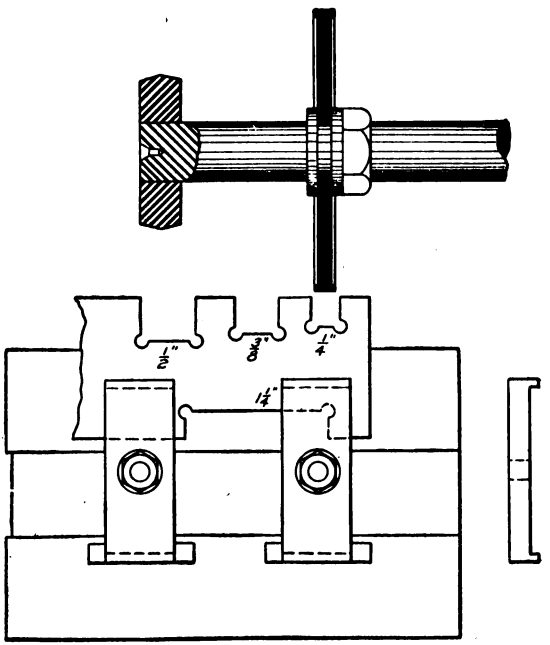


Fig. 432. Method of Fastening Gage for Grinding with Thin Wheels

may be fastened to the rest, Fig. 432. At the right is shown a side view of one of the straps used to hold the work to the rest while grinding; the center is represented as being cut away in order that it may bear at its ends, thus removing any chance of its tipping the work that is being ground.

Lapping Snap Gages. Where it is essential that gages retain their exact size for a considerable length of time, the gaging surfaces

must be lapped to size after grinding. The surface left by the emery wheel, even when the utmost care is used, consists of a series of small ridges or irregularities which wear away as the gage is used and leave the opening too large. Lapping the gaging surfaces with oil and emery grinds these minute particles away and produces a perfectly flat surface, thereby increasing the durability of the tool.

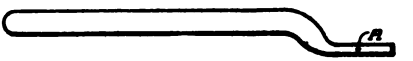


Fig. 433. Lap for Gaging Surfaces

A convenient form of lap to use on snap gages is illustrated in Fig. 433. It consists of a piece of copper or brass wire, bent as shown; the surface *A* is filed or hammered flat, and is charged with some abrasive material, as emery. Extreme care must be used in lapping the surfaces, that they may remain perfectly flat and parallel. Unless the operator has had considerable experience in this particular work, he will be likely to cut the edges away more than the center. To avoid doing this, pieces of hardened steel may be clamped to each side of the gage before grinding, Fig. 434. As the tendency when lapping is to make the outer edges round, the portions rounded

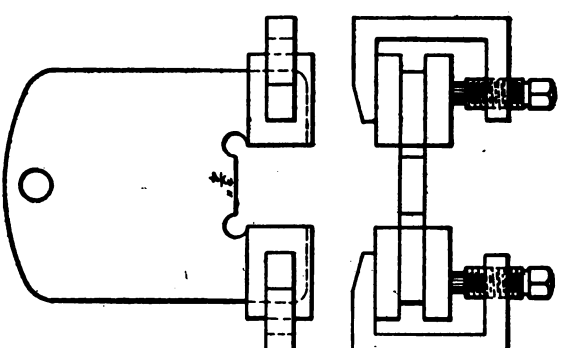


Fig. 434. Method of Clamping Pieces on Gage to Prevent Rounding Edges

will be the edges of the pieces clamped to the gage. After the gage has been lapped to size these pieces may be removed.

Adjustable Snap Gage. Snap gages that are in constant use soon wear to an extent that renders them useless, making it necessary

to close them in, and grind and lap them to size again, or else to replace them with new ones. This tendency to wear, and the consequent labor and cost of resizing or replacing, has caused the adoption of a style of snap gage whose size can be altered when necessary; this form of gage is styled an adjustable snap gage.

The method of adjustment differs in different shops. Fig. 435 represents a form of adjustable snap gage which is not expensive and which gives excellent results, because of the ease of adjustment. After blocking out the gage somewhere near to shape, the screw hole for the adjusting screw *C* should be drilled and tapped, and the slot milled for the adjustable jaw. The jaw should be made, as shown, with a slot, through which the binding screw *D* may pass. The jaw should fit snugly in the slot in the frame, and be placed in

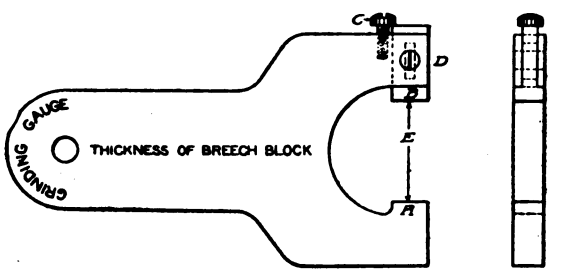


Fig. 435. Adjustable Snap Gage

position after the name and any distinguishing marks are stamped. The aperture *E* should be worked to a size that is from .010 or .015 inch smaller than finish. The adjustable jaw *B* may then be removed, and the gaging, or contact, surface hardened. Care should be taken not to harden the entire length, or a crack may appear in the sharp corners on account of the unequal size of the two parts. In order to heat the contact surface and not to heat back into the sharp corners, the face may be immersed in red-hot lead just long enough to heat the face sufficiently; or the smaller portion may be held in a pair of tongs, letting the end of the jaws come against the shoulders of the piece. It may then be heated in a gas jet or ordinary fire. For most purposes it will be necessary to harden the gage all over; if the gaging portions *A* and *B* are hardened, this will be found

sufficient. After hardening, the gage may be assembled, ground, and lapped, as already explained.

Limit Gages. Where it is not necessary that work be of exact size, and a small degree of variation is permissible, limit gages are used. They prevent a waste of time in attempting excessive accuracy, yet leave the work so that the corresponding parts when brought together will fit well enough to meet requirements. These gages are also valuable in roughing work for finishing. When so used, practically the same amount of stock is left on each piece, thus facilitating the finishing process.

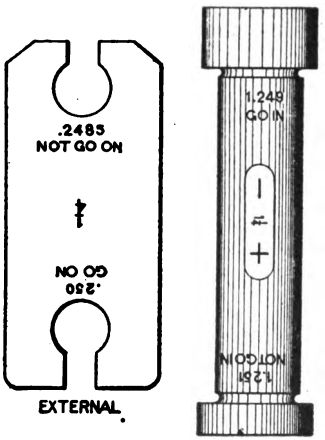


Fig. 436. Simple Snap and Plug Limit Gages

If a cylindrical piece is to go in a reamed hole, and the piece fits well enough for all requirements when .003 inch smaller than the size of the hole, it is folly to spend the time necessary to get a more exact fit. The amount of variation allowable must be decided in each case; on one job a limit of variation of .001 inch might be all that could be allowed, while on another piece of work .010 inch might be allowable.

Fig. 437. Plug Gage

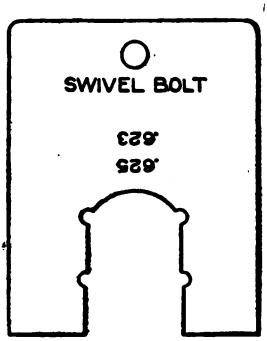


Fig. 438. Snap Gage

In deciding the allowable limit of variation, it is advisable, where possible, to take into consideration the natural changes that take place in the gage from wear. For instance, suppose a piece of work .250 inch in diameter just fills the hole for which it is designed,

and a limit of .0015 inch is allowable; if the piece is from .2485 inch to .250 inch in diameter, it would be folly to make the large end of limit gage for this work .250 inch, as there would be no allowance for wear of either the external or internal gage. The general instructions given for making plug gages and snap gages apply to limit gages of the same character.

Illustrations of Snap and Plug Limit Gages. Fig. 436 gives an idea of one form of snap and plug gage used for external and internal measurements; however, it is not necessary to make them of the styles shown. The plug gage may be made as shown in

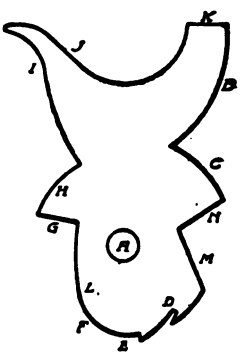


Fig. 439. Diagram of Gun Hammer

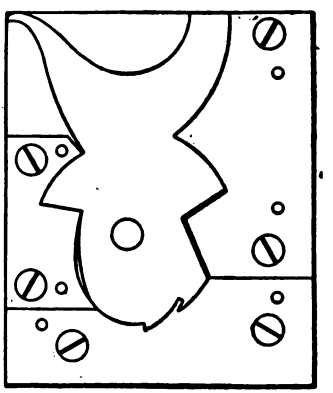


Fig. 440. Receiving Gage for Gun Hammer

Fig. 437; while the snap gage may be made like the one illustrated in Fig. 438.

Receiving Gages. When it is essential that the various working points of a tool, part of a machine, or apparatus shall be in exact relation to one or more given points, a receiving gage is used. This gage, as the name implies, is made to receive, or take in, the work; that is, the piece of work is placed in the gage, and the location of the different points is determined by the eye.

Fig. 439 shows a gun hammer, while Fig. 440 represents a receiving gage for accurately gaging the points *C*, *D*, *E*, *F*, *G*, and *H*, in relation to the fulcrum screw hole *A* and the face *B*. These points must also be in exact relation to each other—hence the

necessity for a gage of this character. When making the gage, it is customary in most shops to gage only those parts that must be located accurately with relation to some other point or points.

Locating Points. In the case of the gun hammer under consideration, the fulcrum screw hole *A* must be the main working point, because when in use the gun hammer is pivoted at this point, and, consequently, every point must be in exact relation to this hole; the point of next importance is the face *B* which strikes the firing pin. In order that the face of the hammer may be the proper distance from the firing pin when half-cocked or full-cocked, it is necessary that the half-cock notch *D*, and the full-cock notch *E* be correctly located with regard to the face of the hammer. They must also be in exact location as regards the fulcrum screw hole *A*. If the main spring is to exert the proper amount of force on the hammer, it is necessary that the spring seat *G* be accurately located. As the portions marked *C* and *H* are intended just to fill the opening in the gun frame when the hammer is in any position, it is necessary that they be located the proper distance from the center of the fulcrum screw hole *A;* hence the need of a gage that will determine the exact location of all points as related to *A* and *B* and to each other. As the portions marked *I*, *J*, *K*, *L*, *M*, and *N* must be in precise location to the other points or to each other, they are gaged with a separate tool because each additional gaging point complicates matters.

Making Base for Gage. When gages of this character are being made, a piece of machine steel is usually taken for the base; this is planed to size and ground or filed for finish; a hole is drilled and reamed to receive a pin the size of the fulcrum screw hole. This pin is made of a piece of drill rod a few thousandths of an inch larger than the desired pin. The piece of drill rod should be long enough to be held in the chuck of the grinding machine, and should be cut of the proper length, as shown in Fig. 441. The short end should be hardened and the temper drawn to a straw color, after which the pin may be placed in the chuck and ground to the desired size. It may then be broken off and the end ground; this can be done by holding the pin in the chuck, leaving the broken end out in order that it may be ground square; the pin should then be forced to place in the hole in the base.

Shaping Gage. The gage proper may be made of one plate worked to the proper shape, but better results follow if it is made in three pieces, as shown in Fig. 440, on account of the tendency of the plate to spring when hardened. The plates may be made either of tool steel or machine steel. If of tool steel, they should be machined all over and thoroughly annealed, then planed or milled to thickness. One surface should be colored by the blue vitriol solution, or the pieces may be heated until a distinct blue color appears; the desired shape should be marked on the colored surface, and the pieces machined and filed until they fit the model, the necessary degree of accuracy being determined by the nature of the work.

Fig. 441. Base Pin for Receiving Gage

Fitting to Base. After the pieces are properly fitted to the model, they may be attached to the base by means of the fillister head cap screws shown. The model should be laid on the base having the fulcrum screw hole on the pin, and when in its proper

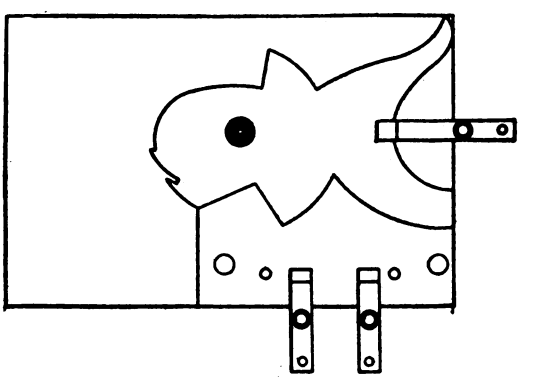


Fig. 442. Model of Gun Hammer Clamped in Place

location, it may be clamped, as shown in Fig. 442. The sections of the gage, which should have been previously drilled for the screw and dowel pins, may now be clamped to the base in their proper positions. After drilling, the holes in the base may be tapped,

and the screws put in place. Slight alterations in any of the shapes are readily made if necessary, as the plates can be moved a trifle since the bodies of the screws need not fit tightly in the holes in the plates. The dowel pinholes should not be transferred into the base until after the plates are hardened.

Hardening. The plates may now be removed and hardened. If of machine steel, they may be casehardened, and dipped in oil rather than water. If made of tool steel, best results follow if they are pack hardened; they should be run from 1 hour to 1½ hours after becoming red hot, and then dipped in raw linseed oil. If the process of pack hardening cannot be used, satisfactory results may be obtained by heating the plates in a tube in an open fire, or placed in the muffle of a muffle furnace. When red hot sprinkle a small

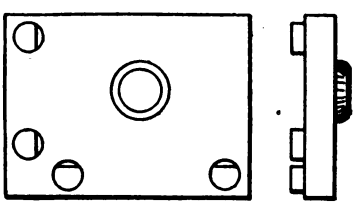


Fig. 443. Locating Gage

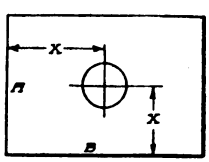


Fig. 444. Piece with Hole to Be Located

quantity of finely powdered cyanide of potassium, or a little yellow prussiate of potash, on the contact surface; place it in the fire again; bring it to a low red heat, and plunge it into a bath of oil.

Attaching to Base. After being hardened, the plates may be attached to the base by means of the screws. If any of the gaging points have become distorted during the hardening, they may be brought to the proper shape by oil-stoning. When the plates are properly fitted and located in their exact positions, the dowel pin holes may be transferred into the base and the dowel pins put in place.

Locating Gages. This form of gage is used for determining the location of one or more holes in relation to another hole, a shoulder, a working surface, or any similar measurement.

Fig. 443 illustrates a gage for showing the proper location of the hole from the edges *A* and *B*, Fig. 444. It consists of a base

having four pins for the edges *A* and *B* to rest against. These pins are flatted on the contact edges to prevent wearing. The piece of work to be gaged is placed in position and clamped to the gage with machinist's clamps, Fig. 445, and the gage is fastened to the faceplate of the lathe in such a manner that the work can be removed without disturbing the location of the gage

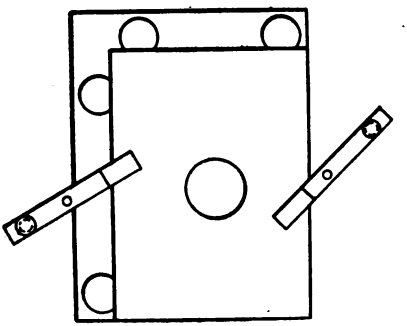


Fig. 445. Piece Clamped in Gage

A short plug, fitting very accurately, is then inserted in the hole in the model. By means of a lathe indicator the gage can be located so that the plug runs perfectly true. When this has been accomplished, the model may be removed and the bushing hole drilled and bored to size, after which the bushing may be made, hardened, ground to size, and forced to place. The location of the drilled hole may be tested by placing the piece of work on the gage against the pins, and entering the gage pin in the hole in the work and bushing, Fig. 446. If the pin is a close fit in the holes, a very slight error in location may be detected. When a slight error is allowable, and it is not considered advisable to hold the location too close, the pin may be made a trifle small, thus transforming the gage into a limit gage.

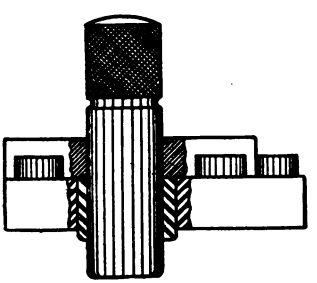


Fig. 446. Gaging Hole

If it is necessary to make a locating gage, for testing the center distance of two holes, one pin may be made removable, while the other is rigidly fixed, as shown at *C*, Fig. 447. If the gage is made with both pins fixed, and the pins are a good fit in the holes, it is a difficult operation to remove the piece of work. Withdrawing

one pin allows the piece of work to be readily taken from the fixed pin.

When making a gage of the form shown in Fig. 447, the fixed pin *C* may be located by approximate measurements; but the hole should be drilled by some method that insures the pin standing perfectly square with the base of the gage. If a small limit of variation is permissible in the center to center measurement *A*, the model may be placed on the gage with the large hole on the fixed pin *C*, and the location of the hole for the movable pin may be transferred from the model by drilling and reaming. If extreme accuracy is essential, it will be advisable to clamp the model to the gage as described, then to fasten the gage to the faceplate of the lathe, place an accurately fitting pin in the small hole in the model, and by means of a lathe indicator locate the gage so that the pin

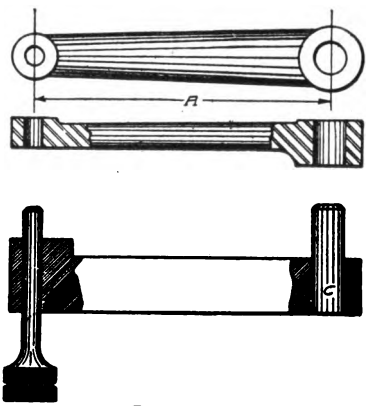


Fig. 447. Simple Form of Locating Gage Showing Method of Use

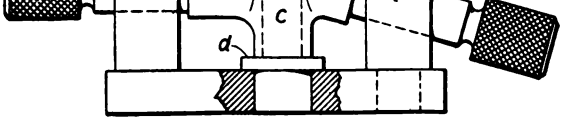


Fig. 448. Gage for Measuring Locations and Directions of Holes

runs perfectly true. The model may then be removed and the hole drilled and bored to size.

Locating gages are made to measure the location of one or more holes from another hole or shoulder, or both. Fig. 448 is a gage to measure the locations of holes *a* and *b* from the hole *c* and

shoulder *d*. The hole *c* is set on a stud solid with the base, and *a* and *b* are gaged by means of the hardened and ground pins shown.

Micrometer Gage. Micrometer locating gages are very commonly used in many shops. They are especially valuable for measuring such pieces as require very close watching, or where a certain variation is permissible, for by means of micrometer readings the amount of variation in thousandths of an inch is easily determined. Fig. 449 shows a micrometer gage used in measuring the angle surface *a* in connection with base *b* and shoulder *c*.

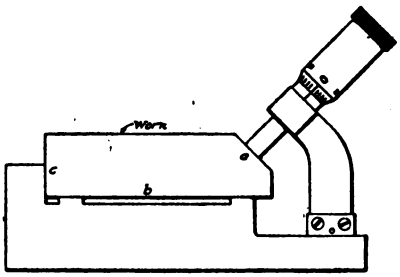


Fig. 449. Micrometer Gage

DRAW-IN CHUCKS

In many shops, the bench lathe plays a very important part in the making of all kinds of small tools. The lathes, being provided with draw-in chucks, allow the extensive use of drill rod when making reamers, counterbores, milling cutters, punches to be used in the punch press, and many other forms of tools. As the modern tool room bench lathe has a milling attachment and a grinding head, it is possible to turn up various forms of tools, and then to do such milling and grinding as is necessary.

While a lathe is usually equipped with an assortment of draw-in chucks to hold stock of various sizes, it is necessary many times to replace a chuck or to make one of special size to accommodate a job that cannot be done in any chuck on hand.

Directions for Making. The methods employed in various shops for making draw-in chucks differ materially, but the following method will be found very satisfactory and does not necessitate special tools:

A piece of tool steel somewhat larger than the largest portion of finished chuck is cut off from $\frac{1}{16}$ inch to $\frac{1}{4}$ inch longer than the finish dimension. After centering, the ends should be carefully

squared and a roughing chip taken. The large clearance hole should now be drilled by holding the end *F*, Fig. 450, in a center rest, and using a drill held in a chuck in the tail spindle of the lathe. Before removing the piece from the center rest, carefully countersink the outer end of the hole with a suitable tool to an angle of 60 degrees.

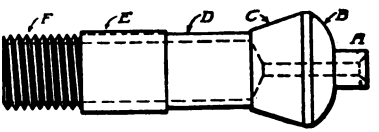


Fig. 450. Draw-In Chuck Blank

The piece is now placed between the centers of a lathe, the portions *B*, *D*, *E*, and *F* turned to finish size, and the thread at *F* cut to fit the threaded hole in the draw-in spindle. The portion *C* is left a little large to allow for grinding after the chuck is hardened.

The portion *A* is turned, as shown, to provide a center for use in turning and grinding; it also holds the chuck in shape when it is hardened as the slots do not extend the length of this portion. The spline cut to receive the feather in the spindle is now milled, the piece being held between the centers of the index head. After the burrs have been removed the piece is inserted in the lathe spindle, and the hole to receive the work is drilled and reamed to a size enough smaller than finish size to allow for grinding after the chuck is hardened.

Fig. 451. End of Draw-In Chuck for Large Drills

The piece is again placed between the index centers and the three slots cut, Fig. 451. As previously stated, these slots should not extend through the portion *A*, Fig. 450, but should be as shown in Fig. 451, and should clear the hole. The slots should extend into portion *E*, Fig. 450, a little way. The metal slitting saw used in producing the slots should be of as small diameter as can be conveniently used, and should not be too thick, as a thick cutter would, in the case of a chuck with a small hole, cut away all the hole. For chucks with large holes, a slot as shown in Fig. 451 works well; but, for chucks with small holes a comparatively thick saw may be used to cut the slot nearly to depth; then a thin cutter may be substituted to finish it as shown in Fig. 452. Before hardening, the

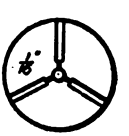


Fig. 452. End of Draw-In Chuck for Small Drills

size of the finish hole should be stamped on the face of the chuck. A finished chuck of this type is shown in Fig. 453.

An oven furnace provides an excellent means of heating for hardening. If an open fire must be used, the chuck should be placed in a piece of gas pipe, heated to a uniform low red, and plunged into a bath of lukewarm water or brine a little above the ends of the slots. The temper of the portions *B* and *C*, Fig. 450, should then be drawn to a brown, and the rest of the hardened part to a blue.

The chuck should now be placed between the centers of a universal grinder, or, in the absence of such a machine, in a grinding

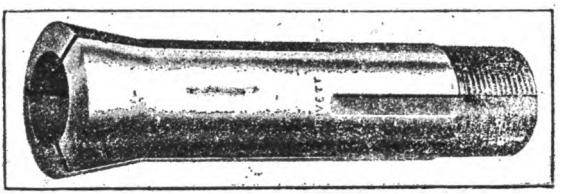


Fig. 453. Completed Draw-In Chuck
Courtesy of Rivett Lathe Manufacturing Company, Boston, Massachusetts

lathe, and the portion *C* ground to finish size and to fit the taper in the nose of the lathe spindle. If many chucks are made, it is advisable to grind to a gage; but, where there are only one or two, it is not necessary to go to the expense of a special gage.

After the portion *C* has been ground to fit, the chuck may be inserted in the spindle of the lathe, the hole ground to size, the portion *A* ground away, and the face polished. The chuck is now ready for use.

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